National Park Service-Klamath Network

Inventory and Monitoring Program

VITAL SIGNS MONITORING PLAN FOR THE KLAMATH NETWORK: PHASE II REPORT

By

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EXECUTIVE SUMMARY

To fulfill its mandate to preserve park natural resources "unimpaired for the enjoyment of future generations," the National Park Service needs current, quantitative information about the status of park ecosystems, their intrinsic variability, and potential threats. To address this need, NPS implemented a strategy known as “vital signs monitoring” to develop scientifically sound information on the status and long-term trends of park ecosystems and to determine how well current management practices are sustaining those ecosystems.

To implement the vital signs monitoring process, 270 National Parks nationwide have been grouped into 32 Vital Signs Networks linked by geographic similarities, common natural resources, and resource protection challenges. The network approach facilitates collaboration, information sharing, and economies of scale in natural resource monitoring. This report describes the initial steps (Phases I & II) in the design of a monitoring program conducted by the Klamath Network.

The Klamath Network (KLMN) encompasses six units managed by the National Park Service in northern California and southern Oregon: Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National and State Parks, and Whiskeytown National Recreation Area. Collectively, the six Park units comprise nearly 200,000 hectares and range considerably in size (196 to 73,775 hectares) and relief. The ecosystems of the Klamath Network are maintained by a complex biophysical environment composed of abiotic processes (climate, geology, and ocean characteristics), biotic processes (competition and predation), and temporal dynamics (disturbances) that span multiple spatial and temporal scales. Humans are both a part of this biophysical system and a source of major threats to it.

The broad goals of the NPS and KLMN vital signs monitoring program are:

1) to determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions;
2) to provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management;
3) to provide data to foster better understanding of the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments;
4) to provide data to meet legal and Congressional mandates related to natural resource protection and visitor enjoyment; and
5) to provide a means of measuring progress towards performance goals.

In pursuit of these goals, the Klamath Network began species inventories in 2000 and is currently certifying species lists for vascular plants, vertebrates and other taxa, and updating natural resource bibliographic and metadata information systems. The network also began the three phase process for developing a monitoring program in 2003. This report chronicles the

Phase I and Phase II processes in the development of a long-term monitoring plan, including descriptions of the biophysical environment of the Klamath parks, monitoring goals, relevant threats and monitoring issues, vital signs selection and prioritization strategies, and prioritized vital signs. In Phase I, the Klamath Network implemented a conceptual model-based strategy to create a natural resources monitoring program. An initial step in this process included the compilation of extensive information about park environments, processes, threats, and management concerns. From this information base, the network and partners developed a list of 33 monitoring questions and over 170 candidate vital signs. In Phase II, the network developed a two-step prioritization process that allowed selection of prioritized vital signs from the comprehensive list identified in the Phase I scoping process.

The most important outcome of the Phase II process was the selection of vital signs with the highest priority for monitoring. This process requires a broad multi-taxa, multi-ecosystem perspective and careful scientific review. In the Klamath Network, we used two steps to prioritize vitals signs: 1) an extensive review with outside scientists in the region, 2) a final internal review by network natural resources staff. The top ten vital signs for the Klamath Network resulting from the two-step process are shown below:

Vital Sign	*Measurable Attribute*
Non-native species	Distribution and abundance of select invasive, non-native plants, animals, and diseases.
Keystone and sensitive plants & animals	Trends in populations of amphibians, whitebark pine, aspen and other keystone and sensitive plants and animals (to be determined, including rare species).
Terrestrial vegetation	Structure, composition and population trends. Focal types include old growth forest, riparian forests, and ponderosa pine forest, early successional vegetation, and special botanical areas (Little Bald Hills, *Puccinellia* springs).
Bird communities	Bird community composition and structure.
Intertidal communities	Intertidal community (e.g. invertebrates and algae) structure and composition.
Freshwater aquatic communities	Composition and structure of freshwater communities (e.g. macroinvertebrates (including mussels) and freshwater vegetation.
Cave collapse / entrance communities	Composition and structure of cave entrance communities.
Water quality (aquatic, marine and subterranean)	Water temperature, chemistry, flow, and pollutant loads.
Land cover, use, pattern (roads)	Changes in land cover and use in and around parks. Road density and use patterns.
Environmental conditions in caves	Temperature, air flow, ice levels.

Sampling design, protocols, databases, Standard Operating Procedures (SOPs) associated with monitoring of each vital sign, and a full program implementation plan will be developed in Phase III, starting in FY 2006. In addition, the Klamath Network is actively working with other networks and interagency partners to identify collaborative and integrative ways to monitor vital signs for which there is broad interest, including non-native plant species (early detection), water quality, vegetation dynamics, bird communities, and high elevation ecosystems.

CHAPTER ONE: INTRODUCTION AND BACKGROUND

The National Park Service (NPS) is charged with preserving some of the nation's most magnificent and beloved lands. Early park service administrators often assumed that the exclusion of logging, grazing, and mining would ensure that, in the words of Horace Albright, second director of the park service, parks would persist in "everlasting wildness." As early as the 1930's, however, occasional scientific studies showed that declines in native species (especially predators), introductions of exotic plants and animals, and impacts from roads were occurring in seemingly pristine areas. Despite anecdotal or sporadic assessments of threats to park ecosystems, a consistent scientific program for monitoring and conserving park resources did not exist for many years. The Natural Resource Challenge, initiated in 1999, is a major initiative to bring scientific knowledge to the parks and the public to ensure that park managers have the best possible science at hand. As the flagship program of the Natural Resource Challenge, the Inventory and Monitoring Program will provide critical information to guide this process. This document lays out the initial goals, objectives, and relevant information for the design of a long-term monitoring program for the Klamath Network parks.

Natural resource monitoring is "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective" (Elzinga et al. 1998, Oakley et al. 2003). This report describes the initial phase of research in preparation of a multi-park monitoring plan for the Klamath Network of National Park Service Units. The purposes of this chapter are to 1) describe the Klamath Network parks and their resources and the environmental setting in which they lie; 2) explain the need for monitoring for changes in resources and supporting environments; 3) identify key information gaps that limit understanding of how to best achieve these monitoring goals. This information is used to develop the conceptual foundation for identifying vital signs to implement monitoring in the Network (see Chapter Two).

1.1. THE KLAMATH NETWORK PARKS

The Klamath Network encompasses six units managed by the National Park Service in northern California and southern Oregon (Table 1.1, Figure 1.1). The USDA Forest Service and USDI Bureau of Land Management have jurisdiction over most lands bordering park Units. In addition, the Bureau of Land Management has authority over the newly created Cascade-Siskiyou National Monument, which falls within the area bounded by the Klamath Network. There are also a number of other agencies and non-profit groups managing and protecting lands within the Klamath region, such as the California Department of Fish and Game (CDFG), and The Nature Conservancy (TNC). To efficiently use all resources available to the Klamath Network Inventory and Management program, interagency collaboration will be essential. This will enable the network to compare trends in diversity and abundance not only within NPS management units, but in surrounding units managed by other state and federal agencies, giving us information that may be indicative of regional ecosystem trends that are important in facilitating ecosystem management.

Collectively, the six existing park units comprise nearly 200,000 hectares with a considerable range in size (196 to 73,775 hectares (484 to 182,298 acres)) and relief (485 to 1602 meters) (Table 1.1). The six parks of the Klamath Network span a region of complex topography that can be split from north to south into two geologically distinct subregions, the Klamath-Siskiyou and the Cascades-Modoc subregions (Figure 1.1). The Klamath-Siskiyou subregion extends eastward from ca. 0.5 km (0.25 mi) offshore in the Pacific Ocean to the edge of the Cascades foothills. The Cascades-Modoc subregion continues eastward into the Great Basin. The parks also vary considerably in the elevations they span (Table 1.1). Nonetheless, there are resource management concerns common to all, including altered fire regimes, both non-native and rare species, impacts from adjacent land practices, and visitor use. There are also park-specific management concerns. Appendix A addresses the specific management concerns of the individual park units, along with a detailed description of the climate, geology, biological, and other resources of each. Appendix D described fire regimes and how they have been impacted, and Appendix E describes the threatened and rare species in the parks, while Appendix C describes vegetation. Here, we provide a brief summary for each park that outlines the park purpose and history, biophysical setting, and major natural resource concerns.

Table 1.1. National Park Service units in the Klamath Network and their size, elevations above sea level, and subregional location (CM = Cascades-Modoc subregion, KS = Klamath-Siskiyou subregion).

Park Unit	Size (ha/acres)	Elevations (m)	Subregion
Crater Lake National Park	73,775/182,298	1219-2720	CM
Lassen Volcanic National Park	43,047/106,369	1585-3187	CM
Lava Beds National Monument	18,898/46,697	1200-1685	CM
Oregon Caves National Monument	196/484	1122-1670	KS
Redwood National Park	42,700/105,469	0-996*	KS
Whiskeytown National Recreation Area	17,614/43,524	244-1893	KS

*The subtidal zone at Redwood National Park extends 0.5 km (0.25 miles) offshore to an unknown depth below mean sea level. The area of marine habitat in the 56 km (35 mile) coastal section of the park is about 2240 ha (5533 acres).

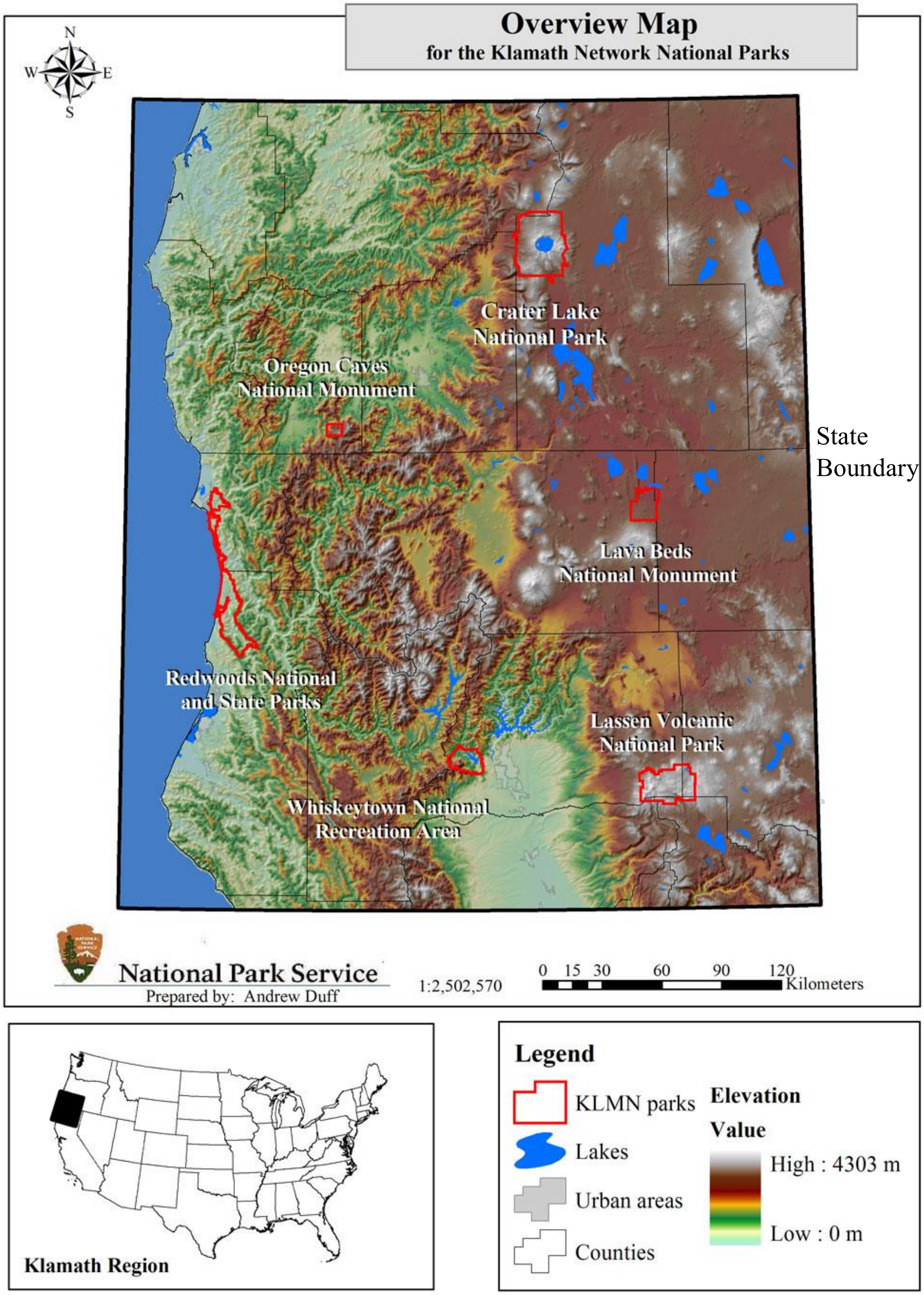
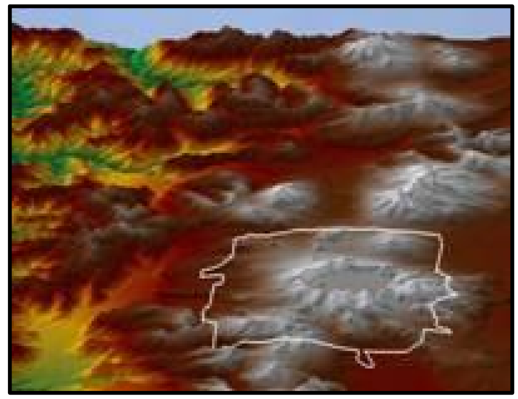


Figure 1.1. National Park units of the Klamath Network of southern Oregon and northern California.

A. Crater Lake National Park

Park Purpose and History



Oblique relief map of Crater Lake National Park showing the Mt. Mazama Crater.

Crater Lake National Park was established by President Theodore Roosevelt on May 22, 1902 (32 Stat. 202) as "an area of two hundred and forty-nine square miles...dedicated and set apart forever as a public (park) or pleasure ground for the benefit of the people of the United States, to be known as Crater Lake National Park." The act further states that adequate measures shall be taken for "the preservation of the natural objects...the protection of the timber...the preservation of all kinds of game and fish" and "that said reservation shall be open...to all...scientists, excursionists, and pleasure seekers."

Biophysical Setting

Crater Lake National Park straddles the divide of the Cascade Mountains (Figure 1.1) with elevations running between 1,219 meters (4,000 feet) and 2,720 meters (8,926 feet). It has a long history of volcanic and glacial activity. Crater Lake occupies the majestic caldera of the former Mount Mazama and is the deepest, clearest lake in the United States. Scientists have also found that the air at Crater Lake National Park is among the cleanest in the United States, making it a Class I airshed. The park has a cool, mesic, but varied climate, and protects outstanding examples of montane and subalpine coniferous forests, high montane meadows and wetland ecosystems, and pumice flats.

Natural Resource Concerns

Maintenance of the pristine air and waters of Crater Lake National Park is a primary park concern. Potential sources of anthropogenic impacts to air and water quality include agricultural field and forestry slash burning, human-ignited prescribed and wildland fires, and air-borne pollutants from local and distant urban and industry areas. The most significant disturbance to geologic features in the park has been road construction, which has resulted in a number of scars to the park landscape. The Pumice Desert is a unique landform that is continually threatened by illegal off-road vehicle impacts that result in unsightly tracks, impacts to sparse vegetation and, possibly, changes in vegetative succession.

Fire suppression and historic logging activities have altered forest structure and species composition throughout portions of the park. Surrounding areas are managed by the Forest Service, where these activities continue resulting in changes in the adjacent landscape. Park managers are concerned about the effects of these changes on plant and animal communities.

Increased harvest and consumptive and recreational use as well as differences in agency policies (e.g., fire management) on the surrounding national forests have led to dramatic changes to Crater Lake's viewsheds, with possibly important effects on terrestrial ecosystem function.

Non-native species--Perhaps the biggest management concern is the non-native pathogen white pine blister rust caused by a true fungus (*Cronartium ribicola*). The white pine species it infects include: western white pine (*Pinus monticola*), sugar pine (*P. lambertiana*), and whitebark pine (*P. albicaulis*), all of which are highly susceptible. As described by Murray (2004), there is much concern about the loss of whitebark pine. It is the only North American representative of the pine subsection *Cembra*e, or stone pines, an exclusive group distinguished by large, wingless seeds within cones that stay closed when ripe. In the Cascade Range, whitebark pine often forms pure stands at timberline, at higher elevations than other trees can tolerate. It extends above timberline in dwarfed (Krummholtz) form. Thus, the pine forms a forested ecosystem where otherwise only meadow or sparsely vegetated slopes would exist at Crater Lake NP.

Blister rust was formally detected on the whitebark pines at Crater Lake in 2000. Based on conservative estimates, infection ranges from zero on the east side to 20% on the west side of Crater Lake's caldera. There are many long-since-dead whitebark pines on the west side of the caldera, indicating that the disease has been present for some time prior to formal detection. Park staff estimate that up to 26% of the park's Westside whitebark pines have been killed by the disease. At current rates, about half of the westside pines will be gone by 2050.

Non-native plants also potentially threaten natural communities. Common mullein (*Verbascum thapsus*), bull thistle (*Cirsium vulgare*) and yellow star thistle (*Centaurea solstitialis*) are presently established, and spotted knapweed (*Centaurea maculosa*) is expected to become a problem. A recent inventory (Appendix I) of the non-native plants in the park (see Appendix I) found that they were directly linked to roadside disturbance.

Non-native animals include fish and birds and bullfrogs (*Rana catesbiana*). Crater Lake originally contained no fish, but was stocked early in the 1900's. Fish planting ended in 1941, and today Rainbow trout (*Oncorhynchus mykiss*) and Kokanee salmon (*Oncorhynchus nerka*) exist in the lake. Brook trout (*Salvelinus fontinalis*) have been planted in Sun Creek, a Klamath River tributary. The Brown-headed Cowbird (*Molothrus ater*) has been found in the park, and Barred Owls (*Strix varia*) are very likely present.

Rare species--Bull trout (*Salvelinus confluentus*) in the Klamath River Basin were listed as "threatened" under the Endangered Species Act by the U.S. Fish and Wildlife Service in June 1998 and the park has made great efforts to restore and maintain a healthy population of the species in Sun Creek. Two other species are listed and threatened, the Bald Eagle (*Haliaeetus leucocephalus*) and the Northern Spotted Owl (*Strix occidentalis*), while there are a host of plants and animals which are not federally protected that are of concern due to relative rarity including mammals such as the fisher (*Martes pennnanti*) and marten (*Martes americana*). (Appendix E).

B. Lassen Volcanic National Park

Park Purpose and History

Lassen Volcanic National Park was established by an Act of Congress on August 9, 1916 "for recreation purposes by the public and for the preservation from injury or spoliation of all timber, mineral deposits and natural curiosities or wonders within said park and their retention in their natural condition...and provide against the wanton destruction of the fish and game found within said park and against their capture or destruction...." Incorporated into the park were Cinder Cone and Lassen Peak National Monuments, which were established by Presidential Proclamations (No. 753 and 754) on May 6, 1907 as part of the Lassen Peak Forest Reserve (established on June 5, 1905 by Presidential Proclamation). In 1972, Congress designated 75 percent of the park (31,964 ha, 78,983 acres) as the Lassen Volcanic Wilderness.

Lassen Peak.

Biophysical Setting

Lassen Volcanic National Park is situated near the junction of the Cascades and Sierra Nevada Ranges with the Great Basin immediately to the east (Figure 1.1). Several types of extinct and dormant volcanoes dominate the landscape alongside active thermal features, such as steam vents and mud pots. Lassen Peak erupted over a six-year period between 1914 and 1921. Preserved within the park is the site of the most recent volcanic eruption within the continental United States, prior to the Mount Saint Helens eruption in May 1980. Lassen Peak is one of the largest plug dome volcanoes in the world. The complex landscape of the park ranges in elevation from 1,585 meters (5,200 feet) in the southeast near Warner Valley to 3,187 meters (10,457 feet) at the summit of Lassen Peak, comprising mid-elevation and subalpine conifer forests, undulating meadowlands, and glaciated alpine terrain. A multitude of streams and lakes occur within the park.

Natural Resource Concerns

Air and water pollution are key management concerns. Lassen Volcanic National Park is a Class I airshed. This designation requires that Federal land managers safeguard air quality from significant deterioration in order to protect air quality-related values. The vitality, significance, and integrity of many park resources are dependent on good air quality. The lack of baseline information about aquatic ecosystems also hinders understanding of human impacts, and is a key management concern in the park.

Several areas of substantial land disturbance exist in the park. These include the now-closed downhill ski area near the Southwest Entrance; the Manzanita Lake developed area, where facilities were removed in the early 1970's because of rock avalanche hazard; several borrow pits along the main park road; Drakesbad Meadow, a very unique fen that was ditched and drained prior to establishment of the park; and an earthen dam at Dream Lake. These disturbed areas are a visual blight, fragment wildlife habitat, disrupt natural water flows and provide opportunities for the establishment of non-native plants.

Along the park boundaries, trespassing by domestic livestock, snowmobiles, and off-highway vehicles is suspected to occur, along with periodic poaching of wildlife within the park (the actual extent of poaching is unknown, but it is thought to be an annual occurrence). Surrounding lands are managed by the US Forest Service. Logging on these lands affects habitat quality for forest dependent species, including rare avian and mammal species that may use the park, such as Northern Goshawk (*Accipiter gentiles*), California Spotted Owl *(Strix occidentalis)* and mammals such as the fisher (*Martes pennnanti*) and marten (*Martes americana*).

Non-native species--Non-native invasive plant species have the potential to overwhelm native ecosystems of Lassen (Appendix I). Approximately 53 exotic plant species occur in the park or immediately adjacent to it, yet only a small portion of the park has been surveyed for introduced plants. Bull thistle (*Cirsium vulgare*), yellow star thistle (*Centaurea solstitialis*), knapweeds (*Centaurea maculosa, C. squarrosa*) and Scotch broom (*Cytisus scoparius*) are the biggest concerns. In terms of non-native pathogens, symptoms and indicators of blister rust on whitebark pine have been observed (Jon Arnold, Pers. Comm.) but the disease has not been confirmed. A recent publication (Meentemeyer et al. 2004) concluded that the northern Sierra, southern Cascades is at high risk for Sudden Oak Death, but this is mainly at elevations below the level of the park.

At least 6 non-native animals occur within the park. These include three fish species: eastern brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutto*), and golden shiner (*Notemigonus crysoleucas*), as well as the European Starling (*Sturnus vulgaris*), the Brown-Headed Cowbird (*Molothrus ater*), and the bullfrog (*Rana catesbiana*). It is likely that other non-native animal species exist, such as Barred Owls, and their impacts are presently unknown.

Rare species--There are no federally listed plant species within the park. However, there are at least twenty-three special status plant species found within the park according to the California Native Plant Society (Appendix E). Almost all of Lassen's special status plants are found in the high elevation subalpine zone. A number of species in the park merit special state and/or federal status due to population and habitat declines throughout their range (Appendix E). For example, Cascades frog (*Rana cascadae*), which was until the mid-1970s considered abundant throughout the park, has been reduced to one very small relict population that does not appear to be reproducing. The Bald Eagle is the sole animal on the Federal list of Threatened and Endangered animal species to occur within the park. A single pair of Bald Eagle nests near Snag Lake, apparently alternating with other nest sites inside or outside the park. Hunting territory for this pair comprises most of the eastern half of the park. Three bird species in the park are currently being considered for federal listing. These are: Willow Flycatcher *(Empidonax traillii*), of the western subspecies group, Northern Goshawk (*Accipiter gentiles*), and California Spotted Owl *(Strix occidentalis)*. Recent studies by the Point Reyes Bird Observatory found that a 2.5 km^2 montane meadow in Warner Valley on the park's south boundary contained one of the state's most significant breeding populations of Willow Flycatcher (King et al. 1998). Northern Goshawk and California Spotted owl have also been shown to depend on Park habitat, but the full extent is not known (Blakesley and Noon 1999, Richter 1998). Two species are on the California Endangered Species List that occur or have occurred within the park are the Willow Flycatcher and the Great Grey Owl (*Strix nebulosa*). The only confirmed sighting of Great Grey Owl occurred near the Bumpass Hell Trail in 1956. Mountain bighorn sheep (*Ovis canadensis*) were previously extirpated. A bighorn reintroduction program was attempted in this area in the 1970's but failed due to a disease outbreak. Other rare mammals believed to be in the park include the fisher (*Martes pennanti*) and marten (*Martes americana*).

C. Lava Beds National Monument

Park Purpose and History

Lava Beds National Monument was established by presidential proclamation No. 1755 on November 21, 1925 (44 Stat. 2591). This proclamation recognized the significance of the area's cultural and natural resources: "Whereas, lands of the United States within the area herein described…contain objects of such historic and scientific interest as to justify their reservation and protection as a National Monument…" Lava Beds National Monument is rich in both natural and cultural resources. Monument lands were home to the Modoc Indians and their ancestors for thousands of years, and were the scene of the Modoc War, which took place during 1872 and 1873.

Biophysical Setting

Lava Beds National Monument lies at a geographic transition zone between the eastern Cascades Range and the Great Basin Desert (Figure 1.1) on the northern flank of the Medicine Lake shield volcano. The monument ranges from 1,200 meters (4,040 feet) at the northern boundary to 1,685 meters (5,529 feet) near the southern boundary. Lava Beds contains excellent examples of recent lava flows, cinder and splatter cones, and over 400 lava tube caves with nearly 47 kilometers (29 miles) of passageway. The monument contains a wide range of Great Basin vegetation communities.

Natural Resource Concerns

Lava Beds is located in a Class I airshed. The air quality of the local area is threatened by wood burning stoves in the local basin, seasonal prescribed and natural fire occurrence, and other impacts. Monitoring of air quality indicators is done throughout the year through cooperative agreements with the California Environmental Protection Agency

Air Quality Board, and an Interagency Monitoring of Protected Visual Environments (IMPROVE) station was installed by the University of California, Davis Crocker Nuclear Lab Air Quality Group in 2000.

Lava Beds National Monument initiated a dark night sky program to preserve the views of the spectacular nighttime skies over the monument. A monitoring program and lighting protocols have been established to guide future management actions in the monument. The night skies would also be negatively impacted by the construction of the Four Mile Hill geothermal plant and transmission lines.

The majority of human visits at Lava Beds National Monument are concentrated in the small fraction of caves that are open and accessible to the general public. These caves bear the brunt of the impact of thousands of visitors each year. The loss of bighorn sheep and changes to lava tube environments resulting from human impact are unique problems for this park unit and are among the chief management concerns.

Non-native species--Lava Beds has a variety of exotic plants to contend with and is taking aggressive measures to inventory and eradicate these species. Several species are currently managed, including common mullein (*Verbascum thapsus*), horehound mint (*Marrubium vulgare*), stinging nettle (*Urtica gracilis*), bull thistle (*Cirsium vulgare*), and yellow sweetclover (*Melilotus officinalis*). Other species such as cheatgrass *(Bromus tectorum*) and tumble mustard (*Sisymbrium altissimum*) are common and at this time and uncontrollable in certain areas of the monument. Canada thistle (*Cirsium canadensis*) and perennial pepperweed (*Lepidium latifolium*) are incipient non-native species problems.

The non-native animals in Lava Beds include the Brown-headed Cowbird (*Molothrus ater*) and European Starling (*Sturnus vulgaris*). Feral horses (*Equus caballas*) roam surrounding areas, but are not found in the monument.

Rare species--Despite the presence of unusual habitats and disjunct species, there are no plant species of special concern due to rarity known from the monument. Federal and state animal species of special concern in the monument include Bald Eagles (*Halioeetus leucocephalus*), Cooper's Hawk (*Accipiter cooperii*), fringed myotis (*Myotis thysanodes*), long-eared myotis (*Myotis evotic*), long-legged myotis (*Myotis volans*), pallid bat (*Antrozous pallidus*), silver-haired bat (*Lasionycteris noctivigans*), Townsend's big-eared bat (*Corynorhinus townsendii*), western small-footed myotis (*Myotis ciliolabrum*), and American badger (*Taxidea taxus*).

D. Oregon Caves National Monument

Park Purpose and History

Oregon Caves National Monument was created by Presidential proclamation in 1909 to protect a three mile cave "of unusual scientific interest and importance." The proclamation states that "…the public interests will be promoted by reserving these caves with as much land as necessary for the proper protection thereof." The monument was transferred to the

National Park Service in 1933. From 1933 to 1942, the Civilian Conservation Corp landscaped a 7-acre National Historic District and put in roads, trails, buildings, and the public water supply. A 1999 general management plan recommended protecting the monument's edges, scenic vistas, caves, and public water supply by adding 1,381 ha (3,410 acres) of adjacent late-successional US Forest Service lands (these lands have not been incorporated in the monument to date).

Biophysical Setting

Cave formations at Oregon Caves National Monument.

Oregon Caves National Monument is a small unit in the steep, mountainous terrain of the Siskiyou Mountains of southwestern Oregon with elevations ranging from 1,122 to 1,670 meters (3,680 to 5,480 ft.) for the main part of the monument. Despite its small size, Oregon Caves is ecologically diverse, due to its relief, high soil and vegetation heterogeneity, and presence of karst cave environments. Old-growth conifer forest, montane meadows, oak woodlands, and cave dwelling species endemic to the monument are resource highlights.

Natural Resource Concerns

Forest fragmentation from the logging of adjacent lands has created effects on vascular plants and vertebrates that are specific management concerns. Global temperature and CO_2 increases are likely changing many aspects of the cave environment, including cave biota, the solutional balance of cave limestone, and the ambient temperatures in the cave rooms. The effects of increasing CO_2 are unknown.

Suppression of fire may have increased the bark beetle, mistletoe, white-fir, and shrub density, as well as decreased the abundance of Douglas-fir, and meadow vegetation. However, a period of 100+ years without evidence of fire occurred prior to fire suppression in the 1600's (Agee 1991).

Non-native species—Port-Orford cedar root rot, caused by *Phytophthora lateralis*, has invaded nearby areas and could kill many of the Port-Orford cedar trees in the monument. Another non-native *Phytophthora* (*P. ramorum*) the cause of Sudden Oak Death could arrive at any time and cause considerable mortality to tan oak (*Lithocapus densiflorus*).

Rare species--No plants with special status are known to live in Oregon Caves National Monument. However, it is home to a number of special status animals (Appendix E), including the federally listed Northern Spotted Owl (*Strix occidentalis*). Five species of concern occur in the cave: Pacific western big-eared bat (*Corynorhinus townsendii*), long-eared myotis (*Myotis evotis*), fringed myotis (*Myotis thysanodes*), long-legged myotis (*Myotis volans*), and Yuma myotis (*Myotis yumanensis*).

E. Redwood National and State Parks

Park Purpose and History

Redwood National Park was established in 1968 and expanded in 1978. Prairie Creek Redwoods State Park was established in 1923, Del Norte Coast Redwoods State Park in 1925, and Jedediah Smith Redwoods State Park in 1929. These parks were established to preserve significant examples of the primeval coastal redwood forests and the prairies, streams, seashore, and woodlands with which they're associated for purposes of public inspiration, enjoyment, and scientific study, and to preserve all related scenic, historical, and recreational values.

Biophysical Setting

Redwood National and State Parks are composed of four units located along the Pacific coast (Figure 1.1). The park is about 81 km (50 miles) long, with 56 km (35 miles) of coastline. The park extends 0.5 km (0.25 miles) offshore for a total of 2,240 ha (5,533 acres) of intertidal and subtidal marine habitat. The prime resources of the park are its 15,782 ha (38,982 acres) of old-growth redwood forests, extraordinary anadromous fish runs, and relatively pristine coastline. Elevations within the park range from sea level to 996 m (3,267 feet) at an unnamed peak in the Coyote Creek drainage.

Aerial view of Redwood National Park and adjacent Pacific Ocean.

Natural Resource Concerns

The old growth redwood forests were the primary resource and purpose for establishment of the Redwood National and State Parks. The parks contain over 20,000 hectares of cutover lands, and much of the parks remain in second growth condition from past logging. These second growth forests lack multi-canopy structure, composition, density, and understory vegetation common in old growth forests. Without active management, a significant portion of the park's forest will likely remain degraded for many years. Park managers need status and trend information to develop an ecologically sound second growth management plan.

Erosion and sedimentation associated with past logging and logging roads threaten the aquatic and riparian resources of certain streams within the parks, primarily Redwood Creek and its tributaries, are of major concern. Of the total estimated erosion potential from all roads within the Redwood Creek basin (5,185,000 cubic meters of sediment), 85 percent is associated with roads upstream of the national park on private timber lands.

These poorly constructed and maintained roads represent a major threat to resources along the main stem of Redwood Creek in the national park. The Redwood Creek federal flood control project levees have altered the physical and biological functioning of the Redwood Creek estuary. This has resulted in major adverse impacts such as decreased water circulation in the estuary and sloughs, fewer deepwater pools, decreased extent of wetlands and riparian habitat, deteriorated water quality, degraded juvenile rearing and adult holding habitat for fish, and reduced wildlife and invertebrate abundance and diversity in the lower Redwood creek valley and estuary. There is great concern over the effects of these numerous impacts on native salmonid fisheries.

The Redwood National and State Parks lack information about the marine plants and animals in tidepools and other intertidal communities, and marine resources in general. The potential impact from offshore ship traffic is a concern because major oil or hazardous material discharge from this activity can pose a serious threat to these marine resources. In order to preserve and manage these unique marine ecosystems, an inventory of these resources is needed.

Non-native species--The impacts of non-native species on native species and communities are a major concern. Baseline data on abundance and distribution of non-native plant and animal species is needed. Cape ivy (*Delairea odorata*) and English ivy (*Hedera helix*) are invading old growth redwood forests, while European beach grass (*Ammophila arenaria*) is displacing potential nesting habitat of the threatened snowy plover (*Charadrius alexandrinus* ssp. *nivosus*). In the Bald Hills habitat of Redwood, non-native annual and perennial grasses have invaded and French and Scotch brooms (*Genista monspessulana* and *Cytisus scoparius*) could become widespread problems. Riparian areas at lower elevation are threatened by Himalaya berry (*Rubus discolor*) and other species. Both Port-Orford cedar root rot (*Phytophthora lateralis*) and Sudden Oak Death (*P. ramorum*) may become problems. The latter has more abundant hosts (e.g. tan oak (*Lithocarpus densiflorus*)).

Barred Owls (*Strix varia*) and bullfrogs (*Rana catesbiana*) have also been found in the park. There are also non-native bullhead (*Ictalurus negulosus*) in Redwood Creek (H. Sakai, pers. Comm.) which could possibly be infected with other marine and freshwater invaders. The park currently contains no known marine invaders. However a small population of mosquito fish (*Gambusia affinis*) was found in Humboldt Bay, about 75 km to the south. Feral pigs (*Sus scrofa*) were previously present at Redwood. Both feral pigs and Wild Turkeys (*Meleagris gallopavo*) could become problems in interior areas of the park in the future.

Rare species—There is one federally listed plant, beach layia (*Layia carnosa*), that is found growing on the dunes in the southern end of Redwood. Fifty-seven sensitive plants have been recognized by the California Native Plant Society which are known or very likely to be found in the park, as shown in Appendix E. Three federally threatened bird species, the Northern Spotted Owl (*Strix occidentalis caurina*), Marbled Murrelet (*Brachyramphus marmoratus*), and Bald Eagle (*Haliaeetus leucocephalus*) are known to reside in the park forests. The Snowy Plover (*Charadrius alexandrinus nivosus*), a threatened species, may occur on beaches in the park. The recently de-listed Peregrine Falcon (*Falco peregrinus*) nests in the park. The federally threatened red-legged frog (*Rana aurora daytonii*) occurs in the park. The endangered leatherback turtle (*Dermochelys coriacea*), threatened Brown Pelican (*Pelecanus occidentalis californicus*), green turtle (*Chelonia mydas*), olive Ridley sea turtle (*Lepidochelys olivacea*), loggerhead turtle (*Caretta caretta*), stellar sea lion (*Eumatopias jubatus*), and the recently de-listed Aleutian Canada Goose (*Branta canadensis leucopareia*) are seasonal transients. The endangered tidewater goby (*Eucyclogobius newberryi*) may still be residing in the Redwood Creek estuary and other estuarine systems within the parks coastal boundaries.

F. Whiskeytown National Recreation Area

Park Purpose and History

The Whiskeytown Unit of the Whiskeytown-Shasta-Trinity National Recreation Area is managed by the National Park Service. The enabling legislation of Congress, which established Whiskeytown on November 8, 1965 under Public Law 89-336, stated that the park was to "provide...for the public outdoor use and enjoyment" of the specified reservoirs and surrounding lands "by present and future generations, and for the conservation of scenic, scientific, historic, and other values contributing to public enjoyment of such lands and water."

Biophysical Setting

Whiskeytown National Recreation Area is located at the southeastern edge of the Klamath Mountains in northern California. Spanning elevations from 244 meters (800 feet) at the southern end of lower Clear Creek, to 1,893 meters (6,209 feet) at the summit of Shasta Bally, Whiskeytown contains an exceptional diversity of plant communities, including a variety of xeric shrublands, oak woodlands, and montane forests that surround the nearly fourteen square-kilometer Whiskeytown Lake. The park is also home to the only known population of the globally imperiled Howell's alkali grass (*Puccinellia howellii*). Seven major streams feed the lake, and the lower reaches of Clear Creek form an important tributary to the Sacramento River, from which anadromous fish come to spawn below the reservoir.

Summit area of Shasta Bally in Whisketown. Huckleberry oak (*Quercus vaccinifolia*) carpets much of the area.

Natural Resource Concerns

Whiskeytown attracts approximately 800,000 visitors per year. Recreational activities in Whiskeytown include boating, swimming, water skiing, sailing, scuba diving, bird watching, fishing, hunting, hiking, horseback riding, mountain biking, camping, picnicking, gold panning, off-road vehicles, and NPS interpretive programs. The population of the nearby city of Redding has grown from 16,000 to 80,000 in the last 20 years, encroaching on habitat near the park. It is expected that as visitor use increases, so will encounters with wildlife. Bear-human incidents and mountain lion-human incidents are of particular concern to land managers.

Prior to the establishment of the park, resource extraction and development impacted the resources of the park's watersheds. Mining for minerals and gravel has resulted in numerous dredge tailing piles, furrows in and around creek beds, and sedimentation of creeks, as well as numerous pits, adits, tunnels, scars, and old roads and trails throughout the park. Logging has occurred on most commercially valuable timberland, and, with generally unstable decomposed granite soils, contributes significant amounts of decomposed granite to creeks and Whiskeytown Lake. In an effort to comply with the Central Valley Improvement Act and to improve anadromous fish habitat, the park staff have implemented an active watershed restoration program to reduce sedimentation of in the watershed. However, the park has insufficient information about its water resources to ensure compliance.

Fire suppression is another major park concern, which managers believe has caused a deterioration of ecosystem health. The increase in tree density, late successional species, and landscape homogeneity that results from fire suppression threatens the stability, diversity, and resilience of mixed conifer forests.

<u>Non-native species</u>--Whiskeytown is host to approximately 170 exotic plant species, which account for approximately 25 percent of the plants in the park. Currently, the most troublesome exotic species in terms of invasiveness are tree of heaven (*Ailanthus altissima)*, yellow starthistle (*Centaurea solstitialis*), Scotch and French broom (*Cystisus scoparius* and *Genista monspessulana*), and Himalayan blackberry (*Rubus discolor)*. Several areas have been successfully treated. Control efforts for the next several years are expected to achieve a significant reduction in exotic plant populations in the park. Treated areas will require monitoring and re-treating indefinitely. The park works cooperatively with the Shasta County Weed Management Area to eradicate exotics across the boundaries of the park. Sudden Oak Death (*Phytophthora ramorum*) could have profound effects on the park, as California black oak (*Quercus kellogii*), which is abundant at mid elevations, is highly susceptible to the disease.

Whiskeytown Reservoir contains five species of introduced fish as potential ecological threats: largemouth bass (*Micropterus salmoides*), spotted bass (*Micropterus punctulatus*), smallmouth bass (*Micropterus dolomieu*), green sunfish (*Lepomis cyanellus*), and brook trout (*Salvelinus fontinalis*). The bullfrog (*Rana catesbiana*) is the dominant amphibian at Whiskeytown Reservoir. There it is believed to be abetted by the non-native fish. Both Cowbirds (*Molothrus ater*) and European Starling (*Sturnus vulgaris*) have been detected at Whiskeytown during network inventories. Feral pigs (*Sus scrofa*) were previously present at Whiskeytown. Both these and wild turkeys (*Meleagris gallopavo*) could become future problems.

1.2. The Need for Long-term Monitoring of Park Lands

The mission of the National Park Service is to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations (National Park Service 1988). In 1992, the National Academy of Sciences analyzed the National Park Service management and concluded that a fundamental metamorphosis was needed. They determined that the development of a standardized program of inventory and monitoring was vital to the mission of the National Park Service. As a result, recent legislation (National Park Omnibus Management Act of 1998) requires that park managers know the condition of natural resources under their stewardship. Therefore, a national strategy for acquiring baseline information and monitoring changes in a science-based fashion has been developed. The strategy has three major components:

1. Completion of basic natural resource inventories in support of future monitoring efforts.
2. Creation of experimental prototype monitoring programs to evaluate alternative monitoring designs and strategies.
3. Implementation of operational vital-signs monitoring in all natural resource parks.

As part of this new program, parks containing significant natural resources were organized into 32 networks, and each network has been asked to develop detailed study plans for the inventory and monitoring of its parks. This document represents the culmination of the process of the development of an integrated, long-term monitoring plan with detailed and precise protocols for the Klamath Network.

The National Park Service has crafted policies in response to federal laws and directives that firmly mandate the linking of inventory, monitoring, and management in order to fulfill the NPS mission to conserve parks unimpaired. Appendix B summarizes the development of these NPS policies and the Klamath Network Charter.

Perhaps the most fundamental question that arises in trying to understand the legislative mandates and the importance and need for monitoring is: **Who is interested in the information provided by monitoring and why?**

Monitoring is critical to adaptive management of park ecosystems in which management actions are viewed as ecological experiments in an iterative process of maintaining or improving ecological integrity. The concept of ecological integrity provides a framework for evaluating changing environmental conditions and biodiversity through monitoring. Ecological integrity refers to ecosystem wholeness, including the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales (Angermeier and Karr 1994; Karr 1991) as well as the environmental conditions that support these taxa and processes (Dale and Breyeler 2001). Human impacts to ecological integrity are assessed based on comparison with reference conditions based on a naturally functioning ecosystem (Karr 1991). The natural range of variability for ecosystems may be impossible to define, so determination of an acceptable range of variation, although imperfect, may be a more attainable goal (Holling and Meffe 1996, Parrish et al. 2003). A broad-based monitoring program, therefore will be an excellent source of information about the integrity of park ecosystem that will grow in value through time.

Monitoring is needed to provide managers not only with assessments of what is changing, but to improve their understanding of park ecosystems. These needs compliment and reinforce each other and also inform park management and research. Well-informed, long-term monitoring of biological and physical phenomena in an integrated, multi-scale fashion across the parks and neighboring landscapes will improve understanding of ecosystems, and can identify additional monitoring and research needs as well as appropriate and scientifically defensible management actions. Thus, the monitoring information is vital to managers and researchers, as well as other individuals and organizations sharing an interest in the Klamath Network Parks and the greater landscape in which they reside.

1.3. STRATEGIC GOALS FOR PERFORMANCE MANAGEMENT (GPRA GOALS)

The Government Performance Results Act (GPRA 1993) insures that daily actions and expenditures of resources are guided by both long-term and short-term goals in pursuit of the park's primary mission. Goals must be quantifiable with measurable outcomes. Table 1.2 illustrates the progress towards major I&M related GPRA goals in the parks of the Klamath Network. The Monitoring Plan for the Klamath Network is a significant and specific step towards fulfilling GPRA Goal Category I (Preserve Park Resources) for this Network. The service-wide goal pertaining to Natural Resource Inventories specifically identifies the strategic objective of inventorying the resources of the parks as an initial step in protecting and preserving park resources (GPRA Goal Ib1). This goal tracks the amount of basic natural resources information that is available to parks and performance is measured by what datasets are obtained.

Table 1.2. GPRA goals specific to KLMN parks and relevant to the long-term network monitoring plan.

GPRA Goal	Goal #	Parks with this goal
Natural and cultural resources and associated values are protected, restored, and maintained in good condition and managed within their broader ecosystem and cultural context.	Category Ia	All
Disturbed lands restored	Ia1A	All
Exotic vegetation contained	Ia1B	All
Threatened and Endangered species and species of special concern	Ia2B, Ia2X	All
Air quality and wilderness values	Ia3	CRLA, LABE, ORCA, REDW, WHIS
Water quality unimpaired	Ia4	REDW, WHIS
Cultural landscapes in good condition	Ia7	All
The National Park Service contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information.	Category Ib	All
Natural resource inventories	Ib1	All
Vital signs for natural resource monitoring identified	Ib3	All
Geologic resources inventory	Ib4A	All
Geologic resources mitigation and protection	Ib4B	LABE, LAVO
Aquatic resources (including cave ice)	Ib5	All

The servicewide I&M Program identified twelve basic inventory datasets as necessary for the foundation of a monitoring program. The service-wide long-term goal is to "acquire or develop 87% of the outstanding datasets identified in 1999 of basic natural resource inventories for all parks". The Klamath Network has made considerable progress on the 12 basic inventories, with the majority of the inventories in the planning phase, underway, or complete as of September, 2004 (Table 1.3).

Table 1.3. Status of 12 Basic Inventories for Klamath Network Parks, August, 2005.

TITLE	PARK CODE					
	CRLA	**LABE**	**LAVO**	**ORCA**	**REDW**	**WHIS**
Air Quality	In Progress	In Progress	In Progress	In Progress	In Progress	In Progress
Air Visibility	In Progress	In Progress	In Progress	In Progress	In Progress	In Progress Work
Cartography	Complete	Complete	Complete	Complete	Complete	Complete
Climate	Partially Complete	Partially Complete	Partially Complete	Partially Complete	Partially Complete	Partially Complete
Geology Map	Scoped 2004, Map In Progress, Bib Completed, Rpt Planned	Scoped 2004, Map In Progress, Bib Complete, Rpt Planned	Scoped 2000, Map IW, Bib Done, Rpt Planned	Scoped 2004, Map In Progress, Bib Complete, Rpt Planned	Scoped 2004, Map In Progress, Bib Complete, Rpt Planned	Scoped 2004, Map Done, Bib Complete, Rpt In Progress
Natural Resource Bibliography	Bib In Progress	Bib In Progress	Bib In Progress	Bib In Progress	Bib In Progress	Bib In Progress
Soils Map	Complete	Planned	Planned	Complete	In Progress	Planned
Species Distribution	In Progress	In Progress	In Progress	In Progress	In Progress	In Progress
Species Lists	6/6 *Certified	6/6 *Certified	6/6 *Certified	6/6 *Certified	6/6 *Certified	6/6 Certified
Vegetation Map	Planning started		Planning started			Near Completion
Water Bodies Map	Planned	Complete	Planned	Planned	Planned	Complete
Water Quality Assessment	Planned	Rpt Complete	Rpt Complete	Rpt Complete	In Work	Rpt Complete

1.4. Formation of the Network and Approach to Planning

A. General Approach to Vital Signs Monitoring

The Klamath Network is following the basic seven step approach to designing a monitoring program, described in detail in the recommended approach for developing a network monitoring program located on the world wide web at http://science.nature.nps.gov/im/monitor/index.htm :

1. Form a network Board of Directors and a Science Advisory Committee.
2. Summarize existing data and understanding.
3. Prepare for and hold a scoping workshop.
4. Write a report on the workshop and have it widely reviewed.
5. Hold meetings to decide on priorities and implementation approaches.
6. Draft the monitoring strategy.
7. Have the monitoring strategy reviewed and approved.

These steps are incorporated into a three-phase planning and design process that has been established for the NPS monitoring program. Phase 1 of the process, which is described in this report, involves assembling the network team, defining the project scope, goals, and objectives that are necessary to execute it; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and completing other background work that must be completed before the initial selection of vital signs for monitoring. Phase 2 of the planning and design effort involves prioritizing and selecting the vital signs that will be included in the network's initial integrated monitoring program. Phase 3 entails the detailed design work needed to implement monitoring, such as developing specific monitoring objectives for each vital sign, sampling protocols, statistical sampling design, a plan for data management and analysis, and determining the type and content of various products of the monitoring effort such as reports and websites.

B. Organizational Structure and Function of the Network

The Network has an eight-member Technical Committee composed of Natural Resource Chiefs from each of the six parks, the Network Coordinator, and the Data Manager. The Committee meets approximately twice each year to discuss and make decisions on the technical aspects of designing and implementing the program, and to find ways to integrate inventory and monitoring with other research or management efforts. The Network’s Inventory and Monitoring Coordinator serves as the chair of the committee. For decisions on permanent hiring of staff, significant allocations of funds, or the overall direction of the program, the Committee makes recommendations to an eleven-member Board of Directors. A Science Advisory Committee composed of the Technical Committee and additional NPS and USGS scientists meet on an *ad-hoc* basis to provide scientific reviews, comments, and advice to the program.

The Board of Directors includes all six park superintendents, two rotating Natural Resource Chiefs, the Regional and Network Inventory and Monitoring Coordinators, and the Pacific Northwest Cooperative Ecosystems Studies Unit (CESU) Coordinator. The Board meets each year following the winter Technical Committee meeting to facilitate fast action on any recommendations. Final authority on the overall program rests with the Board. The bylaws and decision-making process of the Technical Committee and Board of Directors are detailed in a charter signed by superintendents from all six parks. This Charter is presented in Appendix B.

C. Goals for Vital Signs Monitoring

The goal of this program is to identify and monitor vital signs of park ecosystems. The concept is similar to a human health examination, in which critical indicators such as weight, blood pressure, and body temperature help detect health problems and determine remedies or focus diagnostic tests. Similarly, the NPS Vital Signs Monitoring program is intended to monitor key elements of park ecosystems to help detect ecological problems that need further research or management action.

Specifically, Service-wide goals for vital signs monitoring are to:

- Determine status and trends in selected indicators of the condition of park ecosystems to help managers make better-informed decisions and work more effectively with other agencies and individuals for the benefit of park resources.

- Provide early warning of abnormal conditions and impairment of selected resources to promote effective mitigation and reduce management costs.

- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other altered environments.

- Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.

- Provide a means of measuring progress towards performance goals.

The Klamath Network Inventory and Monitoring Program will pursue these goals and further focus the program's effort through the following provisions:

- The majority of funding and efforts will be directed at monitoring vital signs that are relevant to multiple parks and that are best served by the economies of scale provided by the Network program.

- In cases where one or more parks are already monitoring vital signs indicators, and the Network assumes the cost of monitoring, the park agrees to reallocate park-based funds and staff to other natural resource efforts in that park.

- Design the Network program to pursue strategic integration and quality of information for a core set of resource indicators, not simply to provide funding for disparate projects. Additional research and monitoring of park-specific aspects will continue, expanding the core set of Network indicators.

- Strive to maintain strong intercommunication, integration, and where appropriate, cost-sharing between inventory, monitoring, and research efforts in the Network parks. The Network anticipates that monitoring vital-signs status and trends will provide a basis for developing and testing hypotheses for cause-and-effect research. It is the responsibility of the Klamath Network Inventory and Monitoring Program to make key findings available to parks and research partners on reasonably frequent timelines and with adequate clarity. It is the responsibility of the Network's Natural Resource Advisory Committee, Network science staff, and their partners to conceive and locate funding for allied research projects.

- Attempt to work with other NPS networks to develop joint monitoring approaches that are useful to all units in the NPS system that have similar resources or needs.

- Work to maintain close partnerships with other landowners of the Klamath Region to inform them of our inventory, monitoring efforts, and findings. The Network views the national park lands to be among the more protected of the land allocations in each biophysical setting of the region, with value as bellwether sites for measuring synoptic environmental change, as well as reference sites for comparison with more heavily impacted areas.

D. Vital Signs Scoping Process

The process for identifying vital signs has occurred in the parks over the last several years and a network-wide effort began in 2002. Most of the intensive activity occurred spring and summer 2004 and is described in greater detail in Appendix G. This network-wide scoping process involved scoping workshops among resource staff within the parks, outside experts, and Klamath Network Staff.

1.5. BIOPHYSICAL OVERVIEW OF THE KLAMATH NETWORK

The park units of the Klamath Network span a region of exceptional complexity. Steep climatic, geologic, and topographic gradients and varied disturbance regimes yield biological diversity that is exceeded in few similar sized areas within the North American Continent or in temperate regions worldwide. Although the National Park Service manages less than 5% of the Klamath region, the Klamath Network parks contain diverse climates and mosaics of landforms and ecosystems. Across the Network parks, terrestrial habitats range from mesic coastal redwood forests containing biomass accumulations that are among the highest recorded in any terrestrial ecosystem (Fujimori 1977, Sawyer et al.

2000) to barren alpine tundra and xeric sagebrush steppe. Aquatic ecosystems include marine habitats along the Pacific Coast, the deepest natural lake in the U.S., man-made reservoirs, and many streams and rivers. Wetlands are correspondingly diverse with riparian, seep, marsh, fen, and wet meadow types represented. Other unique habitats include karst and volcanic caves, hot springs, and lava flows (Appendix E).

The following sections will briefly discuss the most important non-anthropogenic forces that have shaped the ecosystems of the Klamath region: environmental history, climate and geology, disturbance processes, and biotic interactions.

A. Environmental History: The “Central Significance” of the Klamath Region

Over forty years ago, Whittaker (1961) noted the “central” significance of the Klamath region to Pacific Coast plant geography. This significance is based on the intersection of many widespread western vegetation types and high levels of endemism. There is a greater variety of vegetation in the region than in any equivalent sized region of the western U.S., with Sierran, Vancouverian, Californian, Great Basin, Columbia Plateau, Rocky Mountain, and Colorado Plateau floristic elements represented (McLaughlin 1989). The primary reasons for this floristic diversity appear to be a position at the intersection of major winter and summer airmass boundaries (Mitchell 1976) (Figure 1.2), as well as an ancient landscape with high topographic and geological diversity (Roth 2000). The Klamath-Siskiyou subregion is a globally recognized center of plant paleo-endemism (Whittaker 1961, Stebbins and Major 1965, Smith and Sawyer 1988). Many of the region’s endemic species are associated with unique hydrologic or edaphic sites, such as serpentine soils, rocky outcrops, or wetlands, which provide local refuge from competition or fire (Coleman and Kruckeberg 1999).

Other taxa, such as reptiles and amphibians, also show major northern and southern distributional limits in the Klamath region, leading to high regional richness. However, endemism is relatively low, only two species are endemic (Bury and Pearl 1999), although a new species, the Scott Bar salamander (*Plethodon asupak*) has just been discovered. A number of southern mammal species also reach their northern limits in the Klamath region, such as ringtail (*Bassariscus astutus*), the broad-footed vole (*Scapanus latimanus*), and the Brazilian free-tailed bat (*Tadarida brasiliensis*).

The Klamath and Rogue rivers, two of the three the primary watersheds draining the Klamath region, have also been recognized as a center of endemism for inland fish species (Moyle 1976, Hughes 1987). Snyder (1907) noted the distinctiveness of the Klamath River fauna, and distinguished it from the Columbia River fauna to the north and the Sacramento River fauna to the south. Endemic species, such as the Klamath smallscale sucker (*Catastomus rimiculus),* Pit-Klamath brook lamprey (*Lampetra lethophaga*) and the federally endangered Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) are native to the upper Klamath and Pit River basins. The region also harbors evolutionarily significant runs of chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and steelhead (*Oncorhynchus mykiss*).

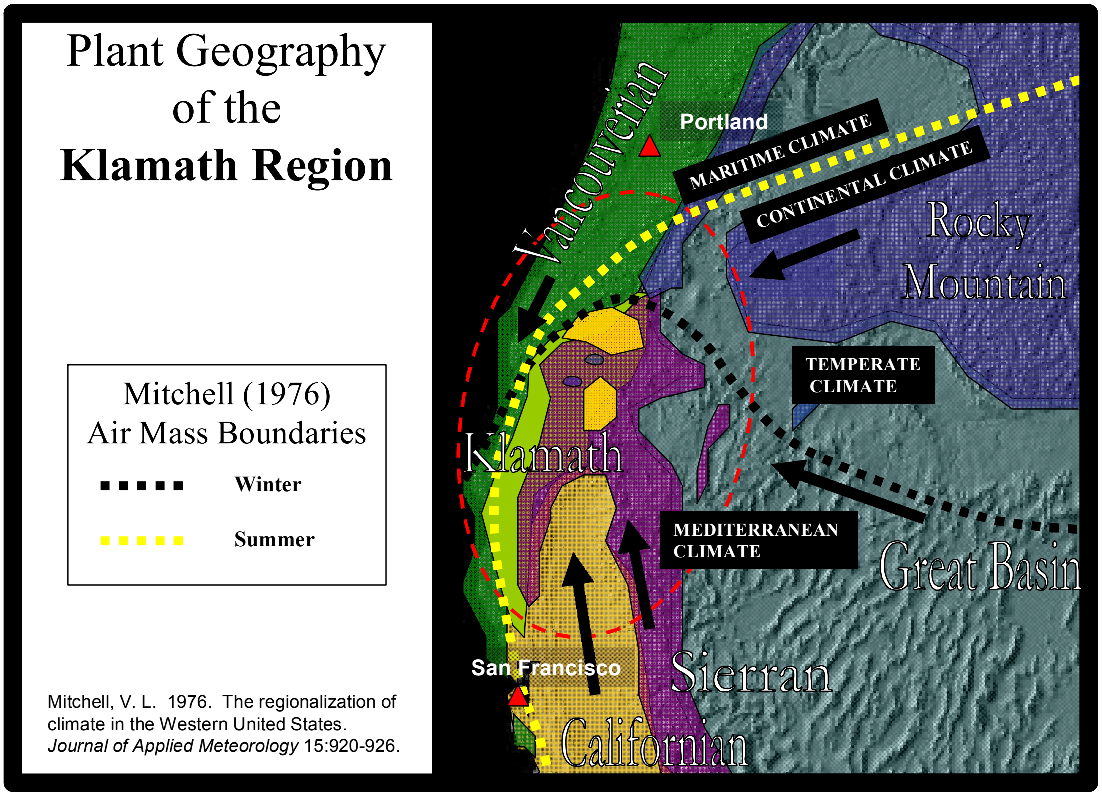


Figure 1.2. This diagram illustrates major floristic provinces influencing the Klamath Region of northern California and southern Oregon and the location of major air mass boundaries outlined by Mitchell (1976).

B. Abiotic Processes

Abiotic processes are critical features of park ecosystems in their own right and because they create the envelope of suitable environmental conditions in temperature, energy, water, and nutrients upon which all life depends (Gates 1980). For plants, abiotic factors have long been known to be fundamental to the distributions of communities (Merriam and Steineger 1890, Clements 1936), as well as individual species (Whittaker 1960, 1965, Walter 1973, Neilson and Wullstein 1983, Woodward 1987, Ohmann and Spies 1998). For other taxa groups, these fundamental controls have typically been less clearly understood, but recent studies suggest they may be very important (Hansen and Rotella 2002). For example, relationships between climate or other physical factors and species distributions or diversity have been noted for birds (Root 1988, Hansen and Rotella 2002), butterflies (Fleishman et al. 1998, Pyle 2002), amphibians (Bury and Pearl 1999), reptiles (Currie 1991, Shrine et al. 2002), and bats (Erickson and West 2002). Consequently, abiotic gradients are believed to be important for interpreting patterns of species diversity and distribution for the majority of life forms. Here, we provide an overview of the abiotic forces affecting Klamath Park ecosystems and their geographic variation.

Climate

The Klamath-Siskiyou subregion, which contains the Redwood, Oregon Caves, and Whiskeytown units, is characterized by extremely rugged topography with elevations ranging from sea-level to over 2,700 m. The high topographic relief and the proximity of the subregion to the Pacific Ocean create exceptionally steep climatic gradients. The climate of the Klamath-Siskiyou subregion is typified by cool, wet winters and warm, dry summers (see Figure 1.3). Particularly important for determining these seasonal climate conditions are the locations and strengths of the Pacific high-pressure and the Aleutian low-pressure systems throughout the year. In winter, the Aleutian low-pressure system is relatively strong and the Pacific high-pressure system is relatively weak. As a result, the prevailing westerlies (i.e., the winds that occur globally at midlatitudes from approximately 30° to 60° north and south) are positioned further to the south and there are increased numbers of cyclonic storms (i.e., storms originating from low-pressure systems) (Bryson and Hare 1974; Miller 2002). These winter storms pick up moisture over the Pacific Ocean and deposit it inland creating cool, wet conditions and provide the majority of the subregion's annual precipitation. Topography also affects the distribution of precipitation, with precipitation generally decreasing in the subregion from higher elevation areas in the west to lower elevation areas in the east (Miller 2002). Despite deep, late-lying snowpacks, winters at high elevations in the Klamath-Siskiyou subregion are relatively mild and the ground rarely freezes.

Old growth redwood forest at Redwood National Park.

In summer, the Pacific high-pressure system is relatively strong, the Aleutian low-pressure system is relatively weak, and the prevailing westerlies and cyclonic storms have shifted northward, creating dry conditions in the Pacific Northwest (Bryson and Hare 1974). As a result, summers in the Klamath-Siskiyou subregion are dry with less than 15% of its annual precipitation occurring between June and September. Along the coast, summer precipitation comes in infrequent, weak frontal disturbances. Away from the coast, summer precipitation occurs as occasional thundershowers, especially in the mountains. Lightning associated with thunderstorms commonly ignites fires in late summer and fall.

Although the Klamath-Siskiyou subregion is strongly moderated by the Pacific Ocean throughout the year, coastal influences are especially marked in summer. From June to September, warm, moist Pacific air is advected eastward by prevailing winds across the cold, upwelling coastal waters of the California current, creating a layer of moist and relatively cool air along the coast (Miller 2002). This moist, cool air is overlain by warmer, drier air, making this moist, marine layer relatively stable. The coastal mountains add to this stability by blocking the moist air from moving inland (Mitchell

1976), although occasionally a “marine push” can develop that will move cool, moist air from the Pacific Ocean over the Coast and Cascade mountain ranges into the interior (Mock 1996). The frequency and length of time a given site is under the influence of this maritime air plays a major role in the ecology of the Klamath-Siskiyou subregion. Maritime stratus and fogs decrease the amount of solar radiation that reaches the ground, lowering maximum temperatures and increasing the humidity during the otherwise dry summers. All these factors differentiate the maritime-influenced western slopes of the Klamath-Siskiyou subregion from the drier eastern slopes (Waring 1969). Coastal slopes and valleys that are favorably oriented to northwest summer winds, are bathed in summer fogs and fog drip that is a vital source of moisture for redwood trees (Burgess and Dawson 2004). These marine air masses effectively delimit the landward extent of the redwood biome.

The Cascades-Modoc subregion, containing the Crater Lake, Lassen Volcanic, and Lava Beds units, is more isolated from the moderating climatic influence of the Pacific Ocean. At low to moderate elevations, summers are warm and dry and winters are cooler than along the coast (see Figure 1.3). The western slopes of the Cascade Mountains receive abundant precipitation from winter storms, with the majority falling as snow at higher elevations. There is a significant increase in storm frequency with latitude in this subregion, such that Crater Lake Park Headquarters receives nearly 50% percent more precipitation days through the year than Lassen Volcanic Park Headquarters. This precipitation difference reflects the latitudinal transition from the Mediterranean climate regime of California to the temperate maritime climate of the Pacific Northwest (Mitchell 1976). Above 2,000 m elevation, snowpacks reach great depths and often cover the ground into summer. Snowfields currently persist year-round on Lassen Peak. The eastern slopes of the Cascades and adjacent Modoc Plateau are much drier, which is reflected in the open vegetation of these areas (as described under Terrestrial Ecosystems, later in this report). During winter, cold continental air frequently invades the Modoc Plateau, but these cold air masses do not often reach the higher elevations of the Cascades or spill over onto the Cascades’ western slopes. Summer thunderstorms are frequent along the Cascades’ crest and eastern slopes in summer.

Geology

The Klamath-Siskiyou subregion is distinguished by its great variety of rock types, including some of the oldest rocks found in the Klamath Network region (Orr and Orr 1999). The region’s extremely complex geology derives from the plate tectonic processes that formed the region. Starting approximately 150-200 million years ago, the North American continental plate began to move west, riding over and subducting beneath it the thinner, heavier ocean plate (Alt and Hyndman 1978; Orr and Orr 1996). As the ocean plate descended under the North American plate, sediment and pieces of ocean crust were scraped off and accreted up against the western edge of the North American continent. Rocks from North America’s coastal plain and continental shelf were also compressed onto the edge of the continent (Alt and Hyndman 1978). The repeated accretion and compression of ocean floor and, in some cases, island archipelago terranes onto the western edge of the North American landmass, created the complex geologic structure of the Klamath-Siskiyou subregion (Wallace 1983). Today, the accreted terranes form a series of convex belts of rocks, decreasing in age from Ordovician (approximately 505 million years old) in the interior to Jurassic (approximately 150 million years old) along the coast (Norris and Webb 1990). These belts form a convex arc whose arms strike southeast towards the Sierra Nevada and northeast towards the Blue Mountains of eastern Oregon (Whittaker 1960; Orr and Orr 1999), approximating the ancient coastal shoreline. Welding and metamorphism by volcanic intrusions, and subsequent warping and folding have further altered these rocks. The result is the distinctive "fruit cake" geology of the subregion, a chaotic mixture of many different types of rocks of different ages, including metavolcanics, gabbros, granodiorite, and ultramafics, such as peridotite (Norris and Webb 1990).

The great variety of rocks found in the Klamath-Siskiyou subregion provide a diversity of substrate habitats for vegetation. Many rocks in the Klamath-Siskiyou subregion are enriched in various minerals. Serpentine soils, which are derived from ultramafic rocks such as serpentinite, peridotite, and dunite, contain high amounts of magnesium, chromium, and nickel (Walker 1954). These soils often sustain rare and endemic plant species (Franklin and Dyrness 1973). A number of the minerals of the Klamath-Siskiyou subregion have also been mined in the past, including chromium, nickel, gold, copper, and zinc (Norris and Webb 1990).

The Cascades-Modoc subregion is of much more recent geologic origin than the Klamath-Siskiyou subregion to the west, and is comprised almost entirely of volcanic extrusive parent materials. This subregion was also shaped by plate tectonic processes. As the ocean plates that formed the Klamath-Siskiyou subregion were subducted deeper below the surface, the rocks forming the plates began to melt. Some of this molten rock escaped back to the surface forming the volcanoes of the Cascade Mountains and the basalt flows that cover much of the Cascades-Modoc subregion (Alt and Hyndman 1978). The rocks that form the current Cascade Mountain Range include basalt, andesite, and dacite (Norris and Webb 1990, Orr et al. 1992). The older, more deeply eroded Western Cascades meet the Klamath-Siskiyou terranes at the western edge of the subregion; the younger High Cascades crest the range with dramatic snowcapped composite volcanoes, such as Mounts Shasta, and McLaughlin. Mount Lassen is a dacite dome, a relatively unique type. Majestic Crater Lake occupies the caldera of Mount Mazama, which exploded cataclysmically approximately 7,700 years ago (Orr and Orr 1996). Many of the high-elevation peaks of the subregion were glaciated at various times during the Pleistocene (0.01-1.8 million years ago) and some, such as Mount Shasta, still have glaciers (Norris and Webb 1990). Along the eastern edge of the Cascade Range are the basalt flows of the Modoc Plateau at 1,000 to 1,500 m elevation. Continued volcanism in this subregion has created a wide variety of geomorphic and geothermal features, including cinder cones, pumice flats, lava plains, lava tubes, hot springs, and fumaroles. The unique hydrogeology of the volcanic landscape allows snowmelt to percolate deep into bedrock aquifers and emerge from numerous springs. As a result, many creeks show very stable baseflows and provide cold water refugia for sensitive aquatic species such as bull trout (*Salvelinus confluentus*).

Water Resources

The aquatic resources within the network are very diverse. Crater Lake is responsible for managing the clearest and seventh deepest caldera lake in the world. In addition, Crater Lake contains deep lake thermal areas. There are also small ponds outside of the Mt. Mazama caldera, numerous streams and springs, and several important wetland areas.

Lassen includes the largest concentration of freshwater lentic systems in the network, with over 250 ponds and lakes (many of which have never been inventoried), as well as several major stream drainages, geothermal areas, and sphagnum bogs along lake margins. Lava Beds has limited surface water, although Tule Lake and the Tule Lake Wildlife Refuge are present near the northern border of the monument. Lava Beds does, however, have approximately 28 known ice caves that are an important source of water for wildlife and, historically, for humans. At Oregon Caves, Cave Creek flows through the main cave and wet meadows and seeps are present in the upper canyon of the creek. Redwood has marine and freshwater aquatic resources. Marine resources include nearshore marine habitat and coastal estuaries and lagoons. Freshwater resources include Redwood and Mill Creeks and their watersheds, and slope fens and seeps. Whiskeytown contains a large reservoir (Whiskeytown Lake) created by the damming of Clear Creek, as well as many perennial and intermittent tributary streams. Historically, mining was a common enterprise within Whiskeytown and as a result acid mine drainage and mercury contamination are of major concern. WHIS also contains the only known global population of Howell's alkali grass (*Puccinellia howellii*), which is restricted to a mesosaline fen in the park.

Other Abiotic Forces

Physical forces, especially the mechanical forces of water, structure the environment strongly. Wave shock, tides and tidal movements and salt spray are very important in coastal environments (Ricketts and Calvin 1939, Bakker 1971). Chemical reactions of solutes precipitating out of solution and forming crystals structures cave environments. Most of these processes are dynamic in nature and are therefore described in a section below, under Dynamic Processes.

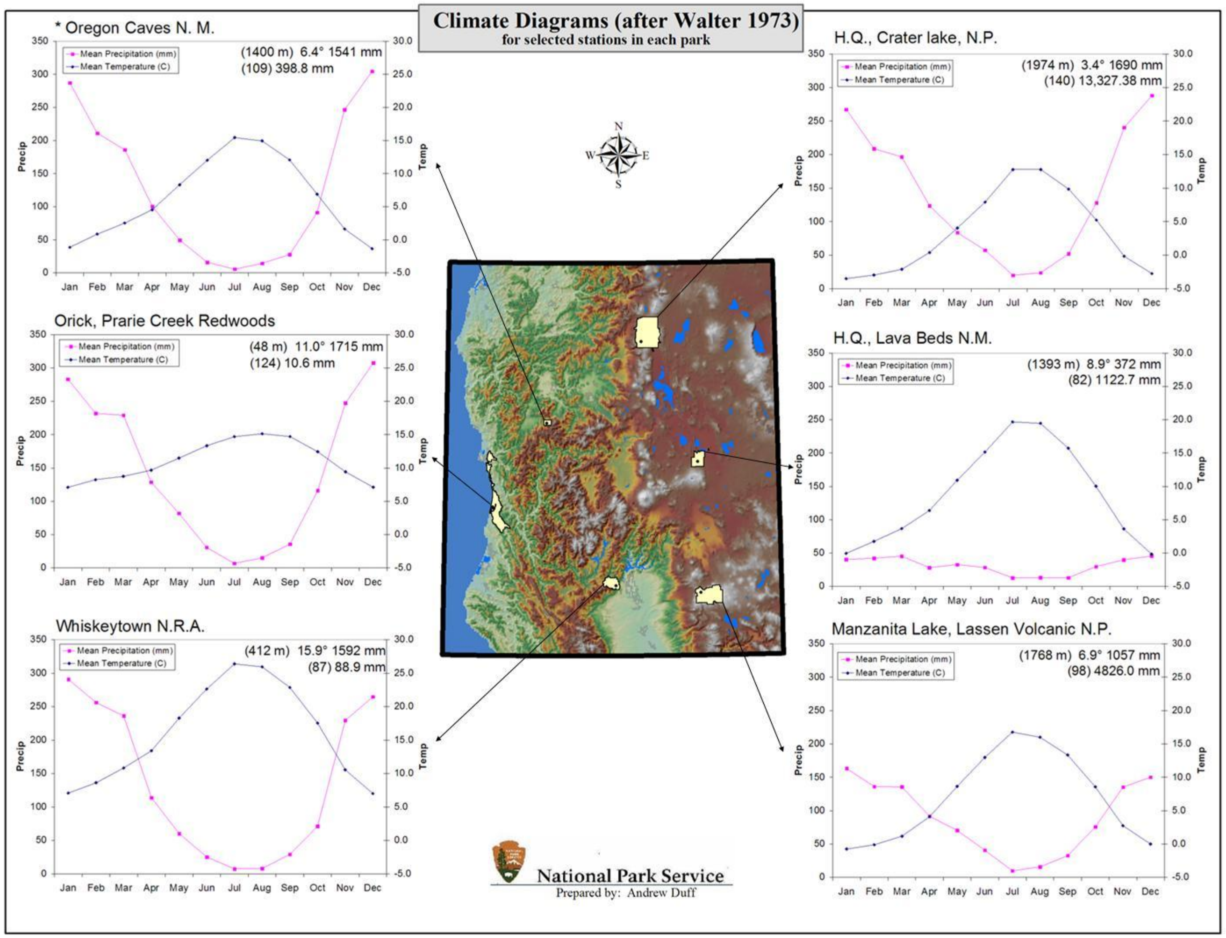


Figure 1.3. Climate diagrams of selected stations in the Klamath Network parks. All parks in the Network show a Mediterranean-type climate regime, with precipitation and temperature regimes perfectly out-of-phase. Summer drought is a defining feature, but is mitigated in units with coastal fogs (Redwood) or late-lying snowpacks (Crater Lake and Lassen). Note the decrease in precipitation and increase in annual temperature variation (continentality) from the westernmost to easternmost parks.

C. Biotic Processes

The biotic environment that unfolds upon the complex physical template provided by the abiotic environment adds another dimension of heterogeneous controls on park ecosystems. In complex landscapes such as the Klamath Region, variation in the abiotic and biotic environment often occurs in concert, yielding ecological zonation. This has long been recognized in terrestrial ecosystems (Merriam and Steineger 1890) and is also clearly evident in aquatic and wetland ecosystems as well (Ricketts and Calvin 1939, Vannote et al. 1980, Mitsch and Gosselink 2000). We employ the zonation concept in the description of ecosystems that follow for several reasons, including: (1) the number of individual ecosystem types in the Klamath Network has never been determined, would likely be too many systems to describe in this report, and would be largely redundant in gradients or dynamics, (2) zonation is consistent with the continuum concept (Gleason 1926) and gradient analysis (Whittaker 1956), which jointly convey the insight that ecosystems are not categorically different, but vary in specific combinations of conditions. This environmental variation often governs species distributions more directly than is implied by discrete ecosystem classifications.

Ecological zonation is clearly evident in all three major ecosystem domains of the Klamath Parks. In terrestrial environments, there is unmistakable variation in plants, animals, and associated species across the major climate gradients from coast to interior as well as along the elevation gradient within a given climate zone. In aquatic environments, zonation is evident in the change in abiotic and biotic conditions from headwaters to downstream and from shorelines to the pelagic zones of lakes. Near-shore environments have some of the sharpest zonation patterns known and described in ecology (Ricketts and Calvin 1939). In all these examples, identification of the abiotic or biotic variables driving change is fundamental to developing a robust monitoring design.

On the other hand, the biotic processes can provide influences that differ from abiotic controls. Successional pathways may diverge autogenically (in other words, by intrinsic biological properties), driven by positive feedback between sessile organisms and their abiotic environment. This may influence the environment to favor established incumbent assemblages over those that would occur strictly under the influence of abiotic factors. For example, plants can influence fire regimes and soil fertility in favor of their maintenance (Jackson 1968, Latham et al. 1996). Positive feedback with fire helps non-native cheatgrass (*Bromus tectorum*) invade and replace Great Basin shrublands (Mack et al. 2000). A self-reinforcing relationship with fire allows patches of native shrub vegetation to persist where conifer vegetation might replace it in the Klamath Mountains (Odion et al. 2004). On the coast, intertidal algae can harbor predators of barnacles and mussels, thereby helping maintain algal beds (Petraitis 1987). In between reinforcing and non-reinforcing extremes are a host of biotic influences having different manifestations.

A grasp of the interactions among trophic levels of organisms is also essential for understanding and maintaining biological diversity. Primary consumers, such as grazing ungulates, free-swimming zooplankton, or benthic grazers pose fundamental controls on the composition and relative abundances of primary producers. This is nowhere more important than in lakes. In Crater Lake and other lakes in the parks major fluctuations in the relative abundances of zooplankton and phytoplankton species and associated lake properties, such as visibility and dissolved oxygen levels, occur over seasons and years. Among primary producers, dominance and diversity relationships appear fundamental for an understanding of spatial and temporal patterns of species diversity as well as the distributions of rare taxa. The highest richness of organisms of many types of primary producers reaches its highest levels in moderately productive environments (Huston 1994, Rosenzweig 1995, Sarr et al. 2005). The mechanisms purported to maintain these patterns are interspecific competition and a dominance hierarchy among native species that involves trade offs between growth rates and stress tolerance (Smith and Huston 1989). At intermediate levels of productivity, many species can coexist. This may be one reason intermediate productivity landscapes, such as in Whiskeytown NRA, have such high floristic diversity.

The roles of insect and avian pollinators and seed dispersers are ever-present and many examples exist to demonstrate their importance. For example, the Clark's nutcracker, a visible and characteristic resident along the rim of Crater Lake, is believed to be an essential dispersal vector for the windless seeds of the whitebark pine (Lanner 1996). Seed caching acorn woodpeckers and squirrels play a similar role for both oaks and pines (Verts and Carraway 1998), and woodpecker acorn granaries are common in oak woodlands of the parks.

There is little doubt that predator and prey interactions are very important in ecosystems where the full complement of species remain such as in the rocky intertidal zone. In terrestrial environments, large predators have been removed, or reduced for many years. Wolves (*Canis lupus*), grizzly bear (*Ursus arctos*), wolverines (*Gulo gulo*), and lynx (*Lynx Canadensis*) are a few of the predator species are known or believe to be extinct in or around the Klamath parks. Mountain lion (*Felis concolor*) populations are rebounding from past depredations. The effects of these major changes in trophic structure are poorly understood.

D. Major Ecosystem Types

Marine Ecosystems

Kelp forest and subtidal habitat at Redwood National Park.

The waters off the Pacific Coast in Redwood National and State Parks are some of the most biologically diverse marine habitats in North America. The park's marine resources depend on the health of the entire ocean ecosystem to support the thousands of floral and faunal species that flourish in these habitats. The marine ecosystem includes areas located within inland, enclosed, nearshore, and offshore waters (Ceres 2004). Five major zones have been described for the nearshore and offshore waters on the coast of California. These five zones include: 1) splash or supralittoral zone, 2) upper midlittoral zone, 3) lower midlittoral zone, 4) lowlittoral or infralittoral fringe, and 5) subtidal zone (adapted from Ricketts and Calvin 1939, Bakker 1971, Kozloff 1973). Each of these micro-elevation zones also has different features depending upon substrate characteristics (e.g., sand vs. rocky substratum). Plants and animals that are more suited to living on land than in the water occupy the splash zone. The plants and animals of the intertidal (littoral zones) are subjected to a range of environmental conditions not encountered in the stability of the deep ocean or subtidal zone, including, substrate, wave shock, relative humidity, air temperature, and exposure to direct sunlight and wind. The specific characteristics of these conditions determine which organisms inhabit intertidal communities. For example, soft substrates, such as sandy beaches and mudflats, support an abundance of burrowing animals, whereas sessile, or attached, organisms are more typical of rocky shores.

Primary producers in these systems include diatoms and dinoflagellates, algae which make their food through photosynthesis. Primary consumers consist of zooplankton such as larval forms of sea animals, copepods, worms, radiolarians, and foraminifers. Secondary consumers feed on animals that eat producers, and include starfish, fish, seals, and sea lions (Bakker 1971).

<u>Marine Flora-</u> The splash zone, species with adaptations to terrestrial life predominate (Bakker 1971). Common shore plants are yellow sand verbena (*Abronia latifolia*), dunegrass (*Leymus mollis*), and beach morning glory (*Calystegia soldanella*). A variety of lichens and algae may be found in this first zone, including *Verrucaria* spp., *Caloplaca* spp., *Xanthoria* spp., and *Physcia* spp.

Additionally, lush growths of algae flourish in California's subtidal zone. California, as well as the rest of the west coast of the United States, has the distinction of possessing one of the world's richest seaweed floras, comparable to that of Japan and Australia (Bakker 1971). The kelp forest is a diverse and complex community that occurs along much of the California coast. Kelp forests are composed of dense stands of large brown algae, giant kelp (predominately bull kelp (*Nereocystis leutkeana*) or bladder kelp (*Macrocystis pyrifera*), with an understory of various red and brown algae. Giant kelp is one of the fastest growing plants known, growing an average of 10 inches a day in the spring. A frond of kelp may eventually reach a height of over 250 feet (Ceres 2004). The fronds, anchored on the rocky sea floor by strong holdfasts, grow upwards towards the surface, buoyed by gas-filled floats.

Rocky intertidal habitat at Redwood National Park.

In the subtidal zone, phytoplankton, the basis of almost all ocean food webs, thrives under nearshore summer conditions. Nutrient rich waters, combined with long sunlight days, cause the phytoplankton to bloom. The resulting abundance increase in phytoplankton causes herbivorous and carnivorous zooplankton populations to expand. These zooplankton provide food for fish, which are consumed by birds and mammals that inhabit these coastal habitats (Bakker 1971).

Marine Fauna- Species commonly observed in the splash or supralittoral zone include rock lice (*Ligia oceanica*), acorn barnacles (*Chthamalus dalli* and *Balanus glandula*) and the limpet (*Collisella digitalis*) (Kozloff 1973). The checkered periwinkle (*Littorina scutulata*) and the gray periwinkle (*Littorina keenae*) can be found in the lower levels of the splash zone where they move about on the rocky faces.

In the intertidal or littoral zones, limpets and barnacles are adapted to withstand fierce wave action. Purple sea urchin (*Strongylocentrotus purpuratus*) can be found in very wave-ridden places where they use their tough spines to scrape rock cavities. Additionally, California mussels (*Mytilus californianus*), common starfish (*Asterias forbesii*), and leaf barnacles (*Pollicipes polymerus*) or gooseneck barnacles (*Lepas anatifera*) inhabit these littoral zones. Many intertidal organisms use rock fissures, overhangs, and other possible refuges to escape wave impact.

Kelp forests provide food and shelter for a number of organisms. The kelp forests are home to diverse invertebrate assemblages, including anemones, abalones, sea stars, urchins, and sea cucumbers. Kelp beds are also home to fish such as the blacksmith (*Chromis punctipinnis*), kelp bass (*Paralabrax clathratus*), and several species of rockfish (*Sebastes* spp.) and surfperch (*Hyperprosopon* spp.). Harbor seals (*Phoca vitulina*) forage the kelp beds for fish. Sea otters (*Enhydra lutris*), a rare mammal, live in the kelp forest canopy, feeding on the abalone, sea urchins, and other invertebrates they catch on the bottom. They are not currently found at Redwood, but could return.

Freshwater Ecosystems

Montane riparian system

The non-marine aquatic environments in the Klamath Network include a diversity of stream, lake, and wetland ecosystems that vary with climate zone and elevation (Table 1.4). In general, the well-watered and steep terrain of the Klamath Parks supports high drainage densities of intermittent and permanent streams but limited areas of wetlands. Most of the stream kilometers in the Network are in headwater streams. Consequently, the parks of the Klamath Network form important water source areas for cities, agriculture, and aquatic species downstream. Several important exceptions to this general pattern are noteworthy. Semi-arid Lava Beds National Monument, with excessively drained fractured lava solids, contains no permanent surface streams. However, the monument does hold ice caves that are important water sources for native species. The undulating backcountry of Lassen Volcanic National Park is unique, with mild topography and many lakes, ponds, and littoral wetlands. The caldera of Mount Mazama that holds Crater Lake is internally drained, though seepage may be an important groundwater source for streams around the caldera margins. Whiskeytown Reservoir, formed by the impoundment of Clear Creek and supplemented with water diverted from the Trinity River, is a large relatively stable and rich lake ecosystem, though the majority of its aquatic vertebrates are introduced species.

With the exceptions noted, the aquatic and wetland environments of the Klamath Parks are dispersed throughout the landscapes. Despite their relatively small areal extent, freshwater ecosystems of the Klamath Network are believed to be critical for landscape diversity wherever they occur.

Lake and Pond (Lentic) Ecosystems- Lake and pond environments are of particular interest in the Klamath Network. Crater Lake is a lentic ecosystem of global significance. However, most of the Network's lakes are in Lassen Volcanic National Park, which contains over 200 temporary to permanent lakes and ponds. Lassen park staff considers these aquatic environments, and the marshes and wet meadows that edge them, to host the majority of the park's biological diversity. Zonation of lakes is similar to the coastal environment in many ways. The primary gradient in lakes is also the transition from the wave-influenced, well-illuminated, and seasonally variable littoral zone to the comparatively stable, but light-poor depths. The depth of the lake and nature of the shoreline also strongly influence the attributes of the water column and the organisms present. This contrast is well expressed by comparing the deep, rock-bottomed, and ultra-oligotrophic Crater Lake, with the shallow, sedge-fringed eutrophic lakes and ponds of the Lassen National Park's highlands. Whiskeytown Reservoir presents another unique suite of monitoring issues, with its fluctuating shoreline, high visitor use, and largely non-indigenous aquatic life.

Stream and River (Lotic) Ecosystems- Flowing water (lotic) ecosystems change predictably from headwaters downstream. The river continuum (Vannote et al. 1980) is an excellent depiction of this pattern that is well expressed in the Klamath parks. Water flow begins in most parks with intermittent springs, perennial springs, or seeps that often support distinctive water chemistry and associated flora and fauna. For example, the alkali wetland at Whiskeytown supports the only known global population of Howell's Alkali grass. Most stream distance in the Network is in relatively high gradient streams that are tightly coupled to the mountain watersheds they drain. At

Crater Lake.

the other extreme of the continuum are estuarine habitats of Redwood Creek and the Klamath River, where dynamics within the water column as well as tidal influences are preeminent. Intermediate sized streams are relatively few in the Klamath parks, but they are of special interest because they have high visitor use as well as high habitat value for sensitive species such as salmonids, amphibians, and riparian birds.

Aquatic macrophyte vegetation at Horseshoe Lake, Lassen Volcanic National Park.

Freshwater Flora- Despite occurring in a region known for its floristic diversity and endemism (Whittaker 1961), the aquatic and wetland flora of the parks remains poorly understood. Many dominant aquatic and riparian plant species have broad regional and continental distributions. These include marshes of broad-leaved cat-tail (*Typha latifolia*) and bulrush (*Scirpus acutus*) at Whiskeytown, and high elevation marshes dominated by beaked sedge (*Carex uticulata*) and inflated sedge (*C. vesicaria*), as well as emergent and submergent communities of water lily (*Nuphar luteum*), buckbean (*Menyanthes trifoliatum*), and aquatic smartweed (*Polygonum amphibium*). However, regionally rare species are often associated with wetlands, such as the California pitcher plant (*Darlingtonia californica*) in Redwood National and State Parks and the white-beaked rush (*Rhynchospora alba*) in Lassen Volcanic National Park. The discovery of the world's only known population of Howell's alkali grass (*Puccinellia howellii*) in a saline seep at Whiskeytown hints at the floristic diversity they contain (Appendix E). The nonvascular aquatic flora also appears to be rich, though it is even less well known. Ultra-oligotrophic Crater Lake has a rich plankton flora and scientists are just beginning to study a ring of bryophytes that occur at intermediate depths (100 to 300 m) depth around the submerged caldera walls. Comparable studies have yet to be implemented in most other lakes ponds and streams of the Network. Unfortunately, non-native plant species are very well established in a number of aquatic and riparian habitats of the Network, and are likely expanding.

Freshwater Fauna- The Klamath region is rich in endemic runs of native salmonids, and these species are still important in the ecology of streams in Redwood National and State Parks (see Appendix A). Anadromous fish including chinook salmon (*Onchyrhynchus tshawytscha*), coho salmon (*Onchyrhynchus kisutch*), and summer steelhead trout (*Onchyrhynchus mykiss gairdneri*) are known to occur in the parks' streams and rivers. Potadromous species, such as bull trout (*Salvelinus confluentus*) occur in Sun Creek of Crater Lake National Park. Amphibian species include Del Norte salamander (*Plethodon elongatus*), Olympic salamander (*Rhyacotriton olympicus*), tailed frog (*Ascaphus truei)* in the cool streams and wetlands near the coast, and yellow-legged frog (*Rana boylii*) and western toad (*Bufo boreas*) in the interior. At higher elevations, fish have historically been absent, while amphibians such as the Cascades frog (*Rana cascadae*), and long-toed salamander (*Ambystoma macrodactylum*) are locally important. The invertebrate fauna is well-studied in Crater Lake (Drake et al. 1990) and Redwood Creek, but relatively little is published for other parks or habitats in the Network.

Table 1.4. Dominant freshwater ecosystems of Klamath Network Parks. Abundance codes are: A = abundant, C = common, and U = uncommon, P = uncommon but prominent, ? = unkown, - = not present.

Ecosystem Type	Park Unit					
	Crater Lake	Lassen Volcanic	Lava Beds	Oregon Caves	Red-wood	Whiskey-town
Stream (Lotic) Ecosystems						
Ephemeral streams	C	C	U	C	C	A
Headwater streams	A	A	-	U	A	A
Gathering (mid-order) streams	C	C	-	-	C	C
Large (high-order) Streams and Rivers	-	-	-	-	U	-
Subterranean streams	-	-	-	P	-	-
Lake and pond (lentic) Ecosystems						
Ephemeral Ponds	U	C	U	-	U	U
Ponds	U	A	-	U	-	-
Lakes	P	A	-	-	-	-
Reservoirs	-	-	-	-	-	P
Ice Caves	-	-	U	-	-	-
Wetland (Palustrine) and Riparian (Riverine) Environments						
Springs and Seeps	C	C	-	C	C	C
Wet Meadows	C	C	-	U	U	U
Riparian Forests	C	C	-	U	C	C
Riparian Shrublands	U	U	-	-	U	U
Alkali Meadows	-	?	-	-	-	U
Geothermal Areas	U	U	-	-	-	-

Aquatic habitats are known to be very important for native wildlife, especially birds and a number of riparian dependent mammals. Many songbirds nest and/or feed in riparian areas. A variety of wading birds and diving and dabbling ducks and cormorants are dependent on aquatic ecosystems. Common riparian-associated birds include the black-headed grosbeak (*Pheucticus melanocephalus*), Bullocks Oriole (*Icterus bullockii*), Common Yellowthroat (*Geothlypis trichas*), Coopers Hawk (*Accipiter cooperii*), Red-Shouldered Hawk (*Buteo lineatus*), Song Sparrow (*Melospiza melodia*), Swainsons Thrush (*Catharus ustulatus*), and Yellow-Breasted Chat (*Icteria virens*). Riparian and wetland-associated mammals include the beaver (*Castor canadensis*), river otter (*Lutra canadensis*), water vole (*Microtus richardsoni*), muskrat (*Ondatra zibethicus*), water shrew (*Sorex patustris*), and mink (*Mustela vison*). Many bat species use the riparian environment for commuting and foraging, including silver-haired bats (*Lasionycteris noctivagans*), and red bats (*Lasiurus blossevillii*). Yuma myotis (*Myotis yumanensis*) are associated with streams, rivers, ponds, or lakes (Whitaker et al. 1977, Zeiner et al. 1990), and have been more closely associated with water than any other North American bat species (Verts and Carraway 1998).

A number of aquatic ecosystems of the network have been degraded by human activities. Table 1.5 shows water bodies that are considered impaired due to degradation.

Table 1.5. Listed impaired (303(d)) water bodies of the Klamath Network.

303(d) Impaired Water/Park	Pollutant/Stressor	TMDL Priority*
Klamath River (Redwood)	Temperature	High
	Nutrients	High
Redwood Creek (Redwood)	Temperature	Low
	Sedimentation/Siltation	Medium
Willow Creek (Whiskeytown)	Metals	Low
Swim Beaches (Whiskeytown)	Bacteria	Low

<u>Terrestrial Vegetation and Flora-</u> Despite the relatively close proximity of the park units to one another, the steep environmental gradients across the region create unique biophysical environments in each park and a great variety of vegetation. We provide a more detailed descriptions of these vegetation types in Appendix C (see also Barbour and Major 1977, Franklin and Dyrness (1988), and Atzet et al. (1996)). In general, the vegetation grades from dense, mesic forests of massive redwood trees (*Sequoia sempervirens*) at the wetter western edge of the region, towards mixed evergreen forests dominated by Douglas-fir (*Pseudotsuga menziesii*) and tanoak (*Lithocarpos densiflorus*) with increasing elevation and distance from the coast. At still-higher elevations in the Klamath-Siskiyou subregion, a variety of conifer forests and subalpine vegetation are common. With descending elevation, woodlands and shrublands in rain shadow areas of the interior valleys of the Klamath-Siskiyou are found.

Lassen Peak

Moving eastward and upward into the southern Cascades, oak woodlands grade into mainly Douglas-fir and mixed conifer forests dominated by ponderosa pine (*Pinus ponderosa*) or white fir (*Abies concolor*). Farther upslope, lodgepole pine (*Pinus contorta* ssp. *contorta*), Shasta red fir (*Abies magnifica* var. *shastensis*) and finally, mountain hemlock (*Tsuga mertensiana*) and whitebark pine (*Pinus albicaulis*) forests dominate the subalpine zone. Peaks that surpass treeline, such as Mt. Lassen, support alpine vegetation. The east slope of the Cascades is much drier, supporting mainly lodgepole and ponderosa pine forests. With decreasing elevation, where the eastern slope of the Cascades approaches the high desert climate of the Columbia Basin and Modoc Plateau, ponderosa pine forests become more open and intergrade with western juniper (*Juniperus occidentalis*) woodlands and sagebrush steppe. At lower elevations, arborescent vegetation gives way entirely to Great Basin shrublands dominated by big sagebrush (*Artemisia tridentata* ssp. *tridentata*), rubber rabbitbrush (*Ericameria nauseosus*), and antelope bitterbrush (*Purshia tridentata*). Less widespread vegetation types that are linked more to edaphic controls, such as montane meadows, riparian communities, and coastal prairies, add greatly to biodiversity where they occur. These general gradient patterns are modified by aspect, soil type, fire, and other disturbances.

Sub-alpine forest

Table 1.6 summarizes the vegetation types and their abundance within the parks. We did not use any single classification systems, but a combination of vegetation types described in Franklin and Dryness (1988) and Barbour and Major (1977).

Table 1.6. Dominant zonal terrestrial vegetation types of Klamath Network Parks. Abundance codes are: A = abundant, C = common, U = uncommon, and ? = unknown.

	Park Unit					
Vegetation Type	Crater Lake	Lassen Volcanic	Lava Beds	Oregon Caves	Red-wood	Whisky-town
Coastal Environments						
Coastal strand and dune	-	-	-	-	C	-
Coastal Prairie	-	-	-	-	U	-
Coastal Forest	-	-	-	-	C	-
Low Elevation Environments						
Redwood Forest	-	-	-	-	A	-
Mixed Evergreen Forest	-	-	-	C	C	C
Oak/Pine Woodlands*	-	U	-	U	C	A
Annual Grassland	-	-	-	-	-	U
Chaparral	-	-	-	-	U	C
Mid Elevation Environments						
Mixed Conifer Pine	A	A	-	U	U	C
Mixed Conifer Fir	A	A	-	A	C	C
Montane Chaparral	-	U	-	U	-	U
Upper Montane Environments						
Subalpine Forest	A	A	-	-	-	U
Montane Meadows	C	C	-	U	-	U
Alpine	C	A	-	-	-	-
Great Basin Environments						
Sagebrush Steppe	-	-	A	-	-	-
Juniper Woodland/Savanna	-	-	A	-	-	-
Ponderosa Pine Woodland	C	U	C	-	-	U
Rosaceous Shrubland	-	-	C	-	-	-
Mesic and Hydric Environments						
Riparian Forests	C	C	-	C	C	C
Freshwater Marsh	-	C	-	-	U	U
Seeps and Springs	C	C	-	U	C	U
Alkali Meadows	-	?	-	-	-	U

*At low elevations, usually dominated by Oregon White Oak (*Quercus garryana*) and at slightly higher to mid-elevations by California black oak (*Q. kellogii*).

Roosevelt Elk (*Cervus elaphus roosevelti*) at Redwood.

<u>Terrestrial Fauna-</u> The terrestrial fauna of the Klamath Region correspond in diversity to vegetation. Large ungulate mammals such as elk and deer are found in all parks. Redwood National and State Parks has a population of Roosevelt Elk (*Cervus elaphus roosevelti*), while Pronghorn (*Antilocapra americana*) is frequently sighted in Lava Beds and occasionally in Crater Lake. The Tehama deer herd, the largest migratory herd of mule deer (*Odocoileus hemionus*) in California, use Lassen highlands in summer. Among the large mammals that have been extirpated are potential keystone species such as grizzly bears (*Ursus arctos horribilis*) and grey wolves (*Canus lupus*), as well as bighorn sheep (*Ovis canadensis*) at Lava Beds. A bighorn sheep reintroduction program was attempted in this area in the 1970's but it failed due to an outbreak of disease from domestic sheep in surrounding areas. The Mountain Lion (*Puma concolor*) is the largest remaining carnivore, and it is still common. Other unusual and charismatic fauna include the wolverine (*Gulo luscus*), which is the second largest member of the weasel family (Musteledae). This species, which can range far and wide, at least occasionally visits Crater Lake National Park. Annual surveys are made by helicopter to find its tracks in the snow. Another uncommon member of the weasel family, the fisher (*Martes pennanti*), may be found at Redwood and surrounding environs. This valuable fur-bearer has been extirpated from much of its range. A wide variety of smaller mammals, including foxes, coyotes, species of rabbits and hares, skunks, raccoons and many species of rodents, bats and shrews live throughout the parks.

The Klamath Region harbors a fascinating and diverse avifauna that mirrors its habitat diversity. Sooty Shearwaters (*Puffinus griseus*) soar over the Pacific Ocean, where, Tufted Puffin (*Fratercula cirrhata*), Black-Footed Albatross (*Diomedea nigripes*), and Brown Pelican (*Pelecanus occidentalis*) frequent the haystack rocks and rough cold surf. Along the beaches and rocky coast, a variety of shorebirds breed, migrate and winter, among which American Oystercatcher (*Haematopus palliatus*), Western Snowy Plover (*Charadrius alexandrinus nivosus),* Black Turnstone (*Arenaria melanocephala*) and Dunlin (*Calidris alpina*) are frequent. This western boundary of the region is occupied by the Marbled Murrelet (*Brachyramphus marmoratus*) as it carries food from its off shore foraging waters towards its nest where nestlings wait as much as 50 miles inland in the Region's old growth conifer stands.

In the cathedral-like redwoods of the region, Swainson's and Varied Thrushes (*Catharus ustulatus* and *Ixoreus naevius* , respectively) and Winter Wrens (*Troglodytes troglodytes*) dwell near the ground and Chestnut-Backed Chickadees (*Poecile rufescens*) and Golden-Kinglets (*Piranga Olivacea*) forage among the treetops in forest stands that they share with the Northern Spotted Owl (*Strix occidentalis caurina*). Oak woodlands form patches adjacent to the redwood forests near the coast and next to the inland mixed-conifer forests. Acorn and Lewis' Woodpeckers (*Melanerpes lewis*), and Bewick's Wrens (*Thryomanes bewickii*), White-Breasted Nuthatch (*Sitta carolinensis*) and Bushtits (*Psaltriparus minimus*) make their homes in these deciduous trees and associated shrubs along with birds as small as the nectar eating Anna's Hummingbird (*Calypte anna*) or as large as the predacious Red-Shouldered Hawk (*Buteo lineatus*).

Hermit and Audubon's Warblers (*Dendroica occidentalis* and *Dendroica (coronata) auduboni*) and Hammond's Flycatcher (*Empidonax hammondii*) are among the birds that characterize the more inland mixed conifer forests. At mid-elevations the conifers mix with hardwood trees including big-leafed maples and tanoaks where Black-Throated Grey warblers (*Sylvia nigrescens*), Black-Headed Grosbeaks (*Pheucticus melanocephalus*), Pacific-Slope Flycatchers (*Empidonax difficilis*) and Cassin's Vireos (*Vireo cassinii*) are abundant. At higher elevations true fir associated birds include Mountain Chickadees (*Poecile gambeli*), Pine Siskins (*Carduelis pinus*), Fox Sparrows (*Passerella iliaca*) and White-Headed Woodpeckers (*Picoides albolarvatus*). Towards the eastern portions of the networks the mountains flatten into great-basin habitats where Vesper Sparrows (*Pooecetes gramineus*), Western Meadowlarks (*Sturnella neglecta*) and Canyon Wrens (*Catherpes mexicanus*) live in the Shrub-steppe and lava flows, and Pygmy Nuthatches (*Sitta pygmaea*) in the ponderosa and Jeffrey Pines. Golden Eagles (*Aquila chrysaetos*) soar majestically above the eastern edge of the region.

The Klamath-Siskiyou region has the highest herptofauna diversity of any similar sized mountainous region in the west (Bury and Pearl 1999). Amphibians are of greatest abundance and diversity in the mesic maritime climates of Redwood National and State Parks, whereas the reptile fauna is most rich and abundant at low- to mid-elevation warm, dry interior valleys, such as at Whiskeytown. The species of terrestrially reproducing amphibians within the Network parks are all from the family Plethodontidae. They include: clouded salamander (*Aneides ferreus*), black salamander (*Aneides flavipunctatus*), California slender salamander (*Batrachoseps attenuatus*), ensatina (*Ensatina eschscholtzii*), Dunn's salamander (*Plethodon dunni*), and Del Norte salamander (*Plethodon elongatus*) (Bury and Pearl 1999, Olson 1991). Some of the more common terrestrial reptiles from Network parks include: northern alligator lizard (*Elgaria coerulea*), Mt. Shasta alligator lizard (*Elgaria coerulea* ssp. *shastensis,* at Whiskeytown), sagebrush lizard (*Sceloporus graciosus*), western fence lizard (*Sceloporus occidentalis*), western skink (*Eumeces skiltonianus*), rubber boa (*Charina bottae*), and racer (*Coluber constrictor*).

Karst caves and lava tubes are interesting subterranean features of the landscape in the Klamath Region. Oregon Caves National Monument is home to a karst cave network, while Lava Beds contain an abundance of lava tubes. Many of the processes occurring within the cave network are greatly influenced by air, water, and food exchange with the upland environment. Although the monument is small in size, it is very rich in biological and geological diversity. Most karst caves are created by erosion, usually when rain water or a stream, slightly acidified by carbon dioxide in the soil, seeps downward through cracks and crevices in layers of limestone (Royo 2004). The mild acid gradually dissolves small passages, and as rainwater continues to enter the system and more limestone is dissolved, the passages become micro-caverns that enlarge, forming caves.

Silver-haired bat, (*Lasionycteris noctivagans*). Captured in Whiskeytown.

Lava Beds National Monument is the site of the largest concentration of lava tube caves in the United States, containing nearly 200 caves (NPS 2004a). Lava tubes are natural conduits through which lava travels beneath the surface of a flow. The lava forms a tube-like cave once flow has ceased. When the 1,000° C lava pours from a volcano, the outer edges and surface of the flow cool rapidly and begin to slow down and harden. This outside layer acts as an insulating material while the rest of the flow beneath remains hot and fast-moving. The flow continues like a river, even though the surface has hardened. When the eruption stops and the lava river drains, a lava tube remains. Many of the tubes at Lava Beds were formed around 30,000 years ago after an eruption at Mammoth Crater located near the southern boundary of the park. However, the monument has both much younger and older tubes.

Sometimes portions of a lava tube's roof may collapse as it cools. These openings allow plants, animals, and precipitation to enter and create a world of life within. A few of the tubes at Lava Beds are ice caves, where rain collects and the air temperature remains constantly at or below freezing. These ice formations provide a year-round source of water for animals that otherwise would have no access to water.

<u>Subterranean Flora-</u> The lava outcrops and lava tube collapse systems support a great diversity of plant life, from an impressive variety of lichens and mosses to plants such as desert sweet (*Chamaebatiaria millefolium*) and the aromatic desert (purple) sage (*Salvia dorrii*). A variety of fern species are present in cave entrances, including the spreading wood fern (*Dryopteris expansa*) and the western swordfern (*Polystichum munitum*). These disjunct populations of ferns are well outside of their climatically-determined range.

Subterranean Fauna- Oregon Caves is home to over 160 cave animal species, including eight of the fifteen bat species found in Oregon: Townsend's big-eared bats (*Corynorhinus townsendii*), big brown bats (*Eptesicus fuscus*), California myotis (*Myotis californicus*), long-eared myotis (*Myotis evotis*), little brown myotis (*Myotis lucifugus*), fringed myotis (*Myotis thysanodes*), long-legged myotis (*Myotis volans*), and Yuma myotis (*Myotis yumanenesis*). At Lava Beds, all of the aforementioned plus six additional species of bats have been documented. These additional bat species include: pallid bat (*Antrozous pallidus*), silver-haired bat (*Lasionycteris noctivigans*), Brazilian free-tailed bat (*Tadarida brasiliensis*), hoary bat (*Lasiurus cinereus*), western small-footed myotis (*Myotis ciliolabrum*), and western pipistrelle (*Pipistrellus hesperus*). Furthermore, Lava Beds is seasonally home to the largest, northern-most population of the Brazilian free-tailed bats in the United States. The massive colony annually numbers in excess of 100,000 adult females, which give birth and nurture their young in one lava tube during the summer months.

Brazilian free tail bat (*Tadarida brasiliensis*) evening fly out from lava tube at Lava Beds.

Many animal species live in the cave mouths and interior passages at Lava Beds, including: the Violet-Green Swallow (*Tachycineta thalassina*), Pacific tree frog (*Hyla regilla*), pika (*Ochotona princeps*), bushy-tailed woodrat (*Neotoma cinerea*), and dusky footed woodrat (*Neotoma fuscipes*). There are at least 30 different known microbes that live in the subterranean features at Oregon Caves. Some produce black manganese stains, and some appear lichen-like, while others create the slippery steps, and some even look like a white clay that often is full of antibiotics. Springtails and some beetles are soil animals that are preadapted to live in caves. The subterranean features of Oregon Caves are also home to tissue moths (*Triphosa haesita*), harvestmen (Order *Opiliones*), woodrats (*Neotoma* sp.), snails and slugs (Order *Neotaenioglossa*) and spiders (Order *Araneide*). There are more than 8 endemic cave species found within Oregon Caves, more than any other cave system in the United States. The age, moderate size, and proximity to organic soils of these caves results in a relatively high biodiversity.

E. Species of Special Concern: Rare, Endangered, and Sensitive Species

Rare, endangered, or sensitive species are a monitoring concern in all parks of the Klamath Network (see Appendix E). These species draw disproportionate attention because they are especially imperiled, are charismatic or otherwise well known, and they are protected by law. Many of these species are threatened by regional factors such as habitat fragmentation, altered fire regimes, agricultural development, and urbanization. In addition, each of the six Network parks has conducted a "vital signs" workshop to determine those key resources that are indicative of ecosystem health. Taxa identified as being of concern to all Network parks include amphibians, Neotropical migratory birds, threatened, endangered, and sensitive plant and animal species, and invasive non-native plants and animals.

Sensitive species may play an important role as indicators of subtle habitat changes associated with management. Amphibians or bryophytes, for example, may be among the most sensitive taxa in forests of the Pacific Northwest, and may illustrate the biological significance of management changes more effectively than other prominent organisms, such as vascular plants.

Preliminary lists of threatened, endangered and sensitive plants and animals for the Network yielded over 200 species and taxa that were either Federal or State listed, or tracked by heritage programs or native plant societies in either California or Oregon (see Appendix E). In addition, specific parks have highlighted species or communities of concern in several parks.

F. Dynamic Processes

Many important dynamic processes may operate as disturbances. Disturbance may be defined as any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Pickett and White 1985). Disturbances affect resource availability and physiological stress for organisms. Disturbances of variable area, frequency, and intensity also enhance habitat heterogeneity and regulate the dominance of highly competitive species, reducing competitive exclusion. Both effects will tend to increase diversity (Huston 1994, Spies and Turner 1999), and in part explain why diversity tends to be greatest with intermediate levels of disturbance (Connell 1978). Managing for appropriate levels of disturbance may be especially important for maintaining biological diversity and ecosystem function in disturbance-adapted ecosystems of the Klamath Parks, such as oak and pine woodlands, riparian zones, and intertidal zones. Disturbance is also a key factor in many exotic species invasions (Appendix I, exotic species threats). Because disturbance is such a major factor shaping ecosystems and it has much potential for being altered by human activities, it will likely figure prominently in monitoring protocols.

Here, we describe natural disturbances for the major ecosystem types, while anthropogenic disturbances are described in Section 1.6:

Aquatic Ecosystems

<u>Marine Ecosystems-</u> The coastal environments of Redwood National and State Parks endure dynamics that span a range of spatial and temporal scales. These processes range from the constant ebb and flow of tides and currents and the annual assault of winter storms and waves, to episodic phenomena such as earthquakes, rockslides, and tsunamis.

The relative importance of these factors varies sharply across the gradient from shore to sea. Along the strand or upper intertidal zone, inundation, desiccation, and the battering of waves and rafted debris (logs) create a unique and often hostile template where aquatic and terrestrial life forms interface. In the middle intertidal zone, inundation is more reliable and the diversity of aquatic organisms increases greatly. Still, the powerful effects of waves and tidal currents strongly govern the spatial and temporal patterns of species abundances in the intertidal zone.

Within the subtidal zone, stability in physical and biological conditions increases greatly, with disruption of biological activity becoming more irregular and episodic. Disturbances such as large storms, minus tides, or more episodic phenomena that affect the larger structural components of the marine ecosystem (for example, the kelp forests) are also likely to have important effects on many other organisms.

<u>Lake and Pond (Lentic) Ecosystems-</u> Although comparatively less dynamic than stream ecosystems, lakes and ponds are subject to a range of natural disturbances. Near shores, wave action results in differences in the flora and fauna populations on the windward vs. leeward shores and convex vs. concave shorelines. Seasonal and interannual variation in climate can substantially change shoreline elevation and consequently affect the flora and fauna of entire lakes or littoral zones. These fluctuations can be substantial. Crater Lake, by far the largest and most stable lake in the network, has experienced fluctuations in surface elevation of over five meters (Redmond 1990). A number of the shallower lakes and ponds in Lassen Volcanic National Park dry up entirely during extended droughts (Arnold 2004). Most of the natural lakes and ponds in the Klamath Network occur at higher elevations where small lakes and ponds freeze over for much of the winter (due to its exceptional depth and volume, Crater Lake rarely freezes). The ice in lakes and ponds is typically superficial, but anchor ice probably forms at least occasionally in the shallower lakes of Lassen Volcanic National Park. Geothermal influences have been noted in water column profiles of Crater Lake (Collier et al.1990), but the effects of these processes on biological communities are presently unknown.

<u>Streams and Other Flowing Waters-</u> The parks of the Klamath Network contain streams that range from snowmelt rivulets to the Klamath River. Along the river continuum (Vannote et al. 1980) from headwater streams toward larger streams and rivers, there is a change in the nature and importance of disturbances (Montgomery 1999). Streams are coupled to the dynamics of the terrestrial landscape, especially in headwater environments. Fires and associated debris flows, mass wasting, and large wood entrainment form infrequent, but important disturbances (Montgomery 1999). As stream size increases, longer, more powerful floods shape and impact the riparian environment and create conditions that may lead to stream channel migration (Vannote et al. 1980). Larger rivers have more stable conditions and permit the persistence of larger, longer lived aquatic fauna. Along the same continuum, changes in the environment through which the stream flows (i.e., climatic, geologic setting) exert effects. At higher elevations, ice formation and avalanches may constitute important disturbances in stream courses. Occasional stream heating may be sufficient to act as a disturbance at low elevations. In summary, the disturbance regime of the stream environment is complex, multi-faceted, and spatially variable.

Maintaining the appropriate disturbance regime for diversity is particularly challenging in stream systems. In degraded watersheds and fish-bearing streams of Klamath parks, limitation of sedimentation is a common management goal. Yet we know that some degree of disturbance is essential to the maintenance of biological diversity (Huston 1979, Nilsson et al. 1989, Sarr et al. 2005). It is also clear that species groups in riparian forests differ in their responses to disturbance. Studies of aquatic macroinvertebrates show that as a whole they are highly mobile and resilient to brief mechanical or chemical disturbances (Lamberti et al. 1991). The effects of such disturbances on other less mobile groups (e.g., amphibians and salmonid fishes) appear to be more severe (Sarr et al. 2005). Moreover, the nature and duration of disturbance appears to be very important, with varying effects across taxa. For example, aquatic macroinvertebrate communities and fish are strongly impacted by protracted or repeated desiccation, whereas amphibians may survive such episodes and flourish in the absence of fish predation.

Most streams in the Klamath Parks are low order, high gradient streams that are closely tied to watershed characteristics through which they flow. Changes in fire regimes and impact from roads are likely to impact water quality and the resident and migratory stream biota in these systems (reviewed in Sarr et al., in press). However, infrequent severe fire was probably an important mechanism for periodically providing a flush of sediment and large wood to the stream systems of the parks (Naiman et al. 1992, May and Gresswell 2003). A more-complete characterization of the natural disturbance regimes of lotic environments would be a valuable foundation upon which to base long-term monitoring.

Terrestrial Ecosystems

Eruption of Mt. Lassen in 1914.

Large, infrequent landscape disturbances such as volcanic eruptions, earthquakes, and tsunamis have been historically important in the Klamath region. The region is home to active volcanoes such as Mt. Lassen, which can erupt episodically and redefine the physical environment of affected areas. Mt. Lassen last erupted in 1917 (Strong 1973). Earthquakes are a significant feature in the coastal region due to the proximity of the San Andreas Fault, just offshore. This major fault separates the North American and Pacific Plates. Earthquake disturbance can lead to extensive landslides. Both earthquakes and associated submarine landslides may trigger tsunamis. Tsunamis affect coastlines, such as at Redwood National and State Parks, and may flood areas many meters above sea level. The last tsunami that affected the northern California Coast occurred in 1964.

Fire can also be a landscape-scale disturbance in the Klamath region. Fire is such an important disturbance that the ecology of most terrestrial ecosystems cannot be understood apart from it (Bond and van Wilgen 1996). The Klamath region has the vegetation, climate, and lightning ignitions for active and dynamic natural fire regimes. These affect too many ecosystem conditions to describe here. Instead we present a summary of what is presently known about fire regimes in the Klamath Region and the considerable gaps in our understanding. (See also Appendix D.) Whittaker (1960) summarized the importance of fire to forest vegetation in the region stretching from Redwood National and State Parks to east of Oregon Caves. He concluded that the forest vegetation " may be regarded as a fire-adapted vegetation of a summer-dry climate, in which fires of varying frequencies and intensities and varying sources—white man, Amerind, and lightning—have for a very long time been part of its environment…. It may be understood in this case that the climax, or fire-climax, condition embodies a degree of population instability and irregularity resulting from fires affecting different areas in a patch-wise fashion at irregular intervals." Such variation allows the coexistence of more habitat types and species than would be possible with a fire regime that is relatively homogeneous in space and time. For example, a regime of relatively frequent fire may eliminate the closed-cone knobcone pine (*Pinus attenuata*) and non-sprouting shrubs.

Jennifer Gibson using a drip torch during burnout operations associated with wildfire in Whiskeytown.

For many vegetation types (for example, grasslands, chaparral, and high elevation forests), fire is stand-replacing, and leaves no record of its frequency. Fire frequency in adjacent vegetation for which there may be estimates may or may not be similar. In addition, tree ring records do not describe past patterns of patchiness created by fire. Thus, Appendix D cannot provide descriptions of patch size or other landscape metrics to describe how mixed- or high-severity fire regimes have structured portions of the Klamath landscape. Complicating matters is the non-equilibrium nature of fire regimes. They have changed constantly throughout the Holocene in the Klamath region (Whitlock et al. 2003). The presettlement Little Ice Age climate has now been replaced by warmer climate associated with fires of greater consequence (Stephenson et al. 1991, Meyer and Pierce 2003). Monitoring plans must be designed with the anticipation that aspects of fire regimes will change, and an acceptable range of variability (Parrish et al. 2003) needs to be defined.

Other sources of disturbance that can open gaps in the forest canopy may be as important as those described above, in terms of affected area over time. These include wind, disease, and insect agents. Gaps in upslope forests are created at rates ranging from 0.2 to 2 percent of a stand per year, which is equivalent to a rotation period of 50-500 years (Runkle 1985, Spies et al. 1990). Gaps may cover 5-30 percent of a forest area at any given time. These gap-forming disturbances, though believed less common in riparian areas than in upslope, are nonetheless widespread and are important for local plant diversity and tree regeneration (Sarr et al., in press). Local fauna, including birds, mammals, and invertebrates, is also believed to respond to this fine-scale heterogeneity in forests (Sarr et al. 2005).

Wind disturbances also open large patches in forests (Hansen and Rotella 1999, Stinton et al. 2000). Climate, landform, stand conditions, disease, and other disturbances, including timber harvest, will increase the frequency of windthrow events. For example, in the western Cascades, Stinton et al. (2000) found that 10 percent of a landscape was affected by windthrow from 1890 through the late 1990s, but less area was affected per year prior to the onset of timber harvest.

Subterranean Ecosystems

Caves are generally stable environments when compared with surface ecosystems, often showing remarkable consistency in temperature and humidity from day to day and year to year. This stability creates conditions for a highly specialized fauna. However, disturbances due to rock falls and flooding of subterranean streams due provide some temporal variability. As one moves closer to the cave mouth, conditions become more variable and may be affected directly or indirectly by surface disturbances. Cave environments are very sensitive to anthropogenic disturbances as described in the following section.

1.6. Human Effects on Park Ecosystems

A. Historical Human Effects in the Klamath Network Parks

Since humans play such large roles for both good and ill in national parks, we must incorporate human desires, needs, and effects into park monitoring. Although scientists are typically inclined to view humans as a source of threats to ecosystems, humans have likely played a role in the ecology of the Klamath parks for millennia. Nearly all the parks of the Klamath Network provided critical resources or ceremonial sites for Native Americans and were often subject to their management practices. For example, aboriginal burning of the prairies and oak savannas of the Bald Hills in Redwood are believed to have been critical for the development of the relatively open habitat currently existing there. Although native peoples apparently avoided Crater Lake itself, they gathered in large numbers at Huckleberry Mountain just west of the lake (York and Duer 2002). Hunting and gathering are still practiced by the Klamath and Yurok Tribes in the Klamath parks. Relationships with native peoples and preservation of cultural sites are central features of cultural resource programs in all the parks.

The attitude of society at large towards the parks has changed drastically from boosterism in the early 20th century to a focus more on conservation today (Sellars 1997). Nonetheless, active use of the parks for recreation and education are fundamental to the mission of the parks in the network. Maintaining the quality of the visitor experience in the parks is a key management concern.

Most of the fundamental threats to parks originate from humans, directly or indirectly, and managers must have accurate information to gauge the effects of management. The following subsection briefly discusses some key human threats to the ecosystem identified for the Klamath Network parks.

B. Ecosystem Threats in the Klamath Network

Non-Native Species

Non-native invasions are an enormous concern to the Park Service and society as a whole because their invasion can potentially disrupt all ecological processes (Mack et al. 2000). All aspects of ecological integrity may be negatively affected when non-native species invade. Their presence, even in limited amounts, affects natural values and historic scenes. The National Park System has long been concerned about non-native species, and has developed management guidance in a number of documents (summarized on the NPS invasive species monitoring resource website located on the world wide web at http://science.nature.nps.gov/im/monitor/invasives.htm).

While it is not possible to describe succinctly all the threats imposed by non-native species to the Klamath Network Parks, we have summarized these threats in this document (Appendix I). The biggest threat posed by invasive non-natives is disruption of entire ecosystems (Mack et al. 2000). Individual species may also be decimated by non-native pathogens, such as occurred with the American chestnut in the eastern United States. Both of these kinds of concerns are present in the Klamath Network.

Non-native plants. These are consistently ranked among the highest priorities for biological inventory in the Klamath Network Parks (Acker et al. 2002). Human manipulations of the parks' environments, especially low-elevation parks such as Redwood and Whiskeytown, have lead to high levels of invasion by non-native plant species. As these plants become strongly dominant, they can alter ecosystem integrity and function by greatly diminishing the abundance of native species (Bossard et al. 2000). There are also a plethora of invasive non-native annual grasses such as cheatgrass that are particular threats because their invasion can be facilitated by positive feedback with fire (Mack and D'Antonio 1998). In general, disturbances favor the establishment of invasive non-native plants (Rejmanek 1989, Hobbs 1991). The combination of disturbance and non-native "propagule pressure" is a very strong predictor of landscape susceptibility to invasion (Keeley et al. 2003).

Bullfrogs (*Rana catesbiana*), a highly invasive exotic animal.

<u>Non-native fauna</u>. The threat of non-native fauna appears to be less serious than that of plants. However, the bullfrog (*Rana catesbeiana*) occurs in all parks except Lava Beds and is one of the chief non-native concerns. The bullfrog has a reputation for preying on, and eventually completely displacing, native amphibians and fish. Most bodies of water in the network also contain non-native fish, mostly as a result of purposeful introductions long ago.

Non-native bird species have expanded into the network. Baseline information on the distribution and abundance of these species, and their effect on native bird species in the parks is lacking. In general, as with plants, the worst problems are expected at lower elevations. The brown-headed cowbird (*Molothrus ater*), Starling (*Sturnus vulgaris*) and Wild Turkeys (*Meleagris gallopalo*) are the most conspicuous interlopers. The Barred Owl (*Strix varia*) is a relatively recent arrival as a result of a range expansion that may be facilitated by the opening of forests.

Mammals appear to be less of a problem than the above faunal groups. Most non-native mammals are associated with human-dominated areas. Feral pigs (*Sus scrofa*) could become a serious problem where oaks are important (e.g. Little Bald Hills and Whiskeytown). Similarly, there are several terrestrial and aquatic invertebrates that have significant potential to invade, and serious consequences are anticipated if they do invade.

<u>Non-native pathogens</u>. There are two ongoing exotic pathogen epidemics in the parks that are severely impacting native species: Port-Orford Cedar root rot, caused by the water mold *Phytophthora lateralis*, and white pine blister rust, caused by the fungus *Cronartium ribicola*. Both the Cedar and at least one white pine (Whitebark pine, *Pinus albicaulis*) that are threatened by these pathogens provide keystone ecosystem functions. Unfortunately, there is another emerging epidemic of concern nearby, Sudden Oak Death (*Phytopthora ramorum*), that also affects species that provide keystone functions, oaks and especially tanoak, which provide acorns that sustain much of their associated wildlife. The ecology of these diseases, and implications for monitoring their effects, are described in Appendix I.

One factor that helps slow the spread of Sudden Oak Death appears to be fire. Moritz and Odion (2005) have documented a striking, highly significant absence of the disease in areas that have burned in recent decades. The relationship is not caused by biased monitoring for the disease away from burns, but instead appears to be related to nutrient and chemical changes that occur in the absence of fire to weaken hosts and favor the pathogen. These changes are reversed by fire.

Chytrid fungal diseases first emerged in 1998. They occur worldwide, so the native vs. non-native status is unclear. They are a serious threat to amphibians, causing their flesh to rot.

Fire Suppression

Fire is a profoundly important ecological process in a number of the terrestrial ecosystems of the parks, where it affects vegetation and important soil and watershed dynamics. Because of the warm dry summers, periodic lightning storms, and steep climate gradients, the Klamath forest had a diversity of historic fire regimes that range from frequent low-severity fires in drier forests and woodlands to less frequent, but more severe burns in cooler, wetter forests and some chaparral communities. The effects of topography further refine burn patterns allowing high vegetation diversity. Over seventy years of fire suppression have considerably altered the natural fire patterns and processes across the region. Park resource managers are concerned with returning natural burning cycles to the parks, but there is great scientific uncertainty associated with restoration of indigenous fire regimes and fuel loadings, as well as the potential interactions between fire and non-native species invasions. Both prescribed and wildland fires can create conditions that promote native plant diversity, but they also favor exotic plant establishment. The combined effects of new competitors and altered fire dynamics may jeopardize the viability of some rare or fire-dependent species. See Appendix D for a more-detailed discussion of fire regimes.

Human/Visitor Use Impacts

Increased visitor use and the associated effects of trampling, roads, and pollution are major concerns in Klamath Parks. Human and/or visitor uses impact the natural environments of our national parks. Visitors may inadvertently or intentionally pollute or degrade rare habitats and subsequently destroy areas crucial to maintain viable populations of rare and endangered species. For this reason it is important to identify areas where these types of habitats exist and direct heavy visitor use away from these habitats.

Human disturbance of lentic environments in the Klamath Network includes effects of private and public watercraft, pollutants, and human traffic on shorelines. Motorized watercraft, in particular, cause substantial changes in the turbidity, wave dynamics, and shoreline dynamics of lakes, which impact planktonic communities in the pelagic zone. Chemical spills are also potential disturbances associated with boating.

Whiskeytown Reservoir presents a unique challenge for park managers. It forms a biologically rich lentic environment where a lotic environment formerly existed. As a National Recreation Area, its managers are charged with accommodating the human uses of the reservoir. However, there is no baseline of biological integrity to maintain in this unnatural feature; the lake pool level is managed by the U.S. Army Corps of Engineers.

Disturbances from human foot traffic, changes in atmospheric conditions from in-cave structures or human breathing, rerouting of water or air flow, and disruptions resulting from the behavior of cave fauna (e.g. bat roosts or hibernacula) are a concern in such stable environments as the karst caves at Oregon Caves and the lava tubes at Lava Beds. Larger scale human influences include purported effects of fire suppression on water flow, and the effects of climate change on cave microclimates and water balance (see Chapter Two).

Tide-pool habitats have also been identified as resources particularly sensitive to visitor use and there is concern that ecological integrity of these environments has diminished at Redwood. Another key visitor impact that has been identified is the disruption of marine mammal behavior and nesting seabirds by watercraft such as kayaks at Redwood. In the more remote areas of the parks, effects are more localized, but can be severe. With increasing visitation, opportunities for encounters between humans and wildlife are more likely. Information on mountain lion (*Felis concolor*) or black bear (*Ursus americanus*) sightings are of rising concern.

Degraded Habitats

The Klamath parks have been impacted by past and present human activities to varying degrees. Degraded sites in the parks include roads, campgrounds, areas of past mining (with associated mercury contamination and acid mine drainage), harvested areas, drained wetlands, a defunct downhill ski area, river impoundment, and residue from past cave development. The effects of these legacies on native biodiversity are varied and largely unknown. The desire to restore formerly degraded habitat, where possible, is a common theme.

Transboundary Issues

Since most of the parks in the network are small to moderate in size, they are especially vulnerable to outside influences. Timber harvest outside park boundaries is believed to influence geophysical processes and the viability of aquatic organisms in parks downstream. Pathogens borne on logging equipment in the surrounding national forest pose a threat to the Port-Orford cedar stands of Oregon Caves. In high elevation parks, such as Lassen and Crater Lake, species such as elk (*Cervus elaphus*) may migrate to lower elevations in winter and be affected from interaction with humans or livestock on private land. Trespassing cattle, off-highway vehicles (OHVs), and snowmobiles occasionally enter parks and affect ecosystems.

More diffuse effects, such as air pollution, may also pose as yet unforeseen threats to park biodiversity. Most of the park units within the Klamath Network are distant from major cities and pollution sources, but they can still experience poor air quality from pollutants such as ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and toxics on occasion. Detrimental effects of pollution have been noted in the Sierra Nevada, and may increasingly threaten as urbanization proceeds in the Rogue and Sacramento valleys. Lassen receives emissions from the Sacramento Valley Air Basin. Monitoring activities have revealed foliar symptoms of ozone injury to both Ponderosa and Jeffrey pine, and recent trends show that ozone levels are increasing in the park. A recent air quality report by the NPS (2002) showed significant degradation (at the 0.15 level) in Lassen for two measures of ozone (average daily 1-hr maximum and annual 4th highest 8-hr average) from 1990-1999. Estimates of sulfur and nitrogen wet deposition in the park are well below the minimum levels generally associated with resource impacts; however, the high elevation lakes of Lassen may be more sensitive to acidification than any other aquatic resources in the western parks (Sullivan et al. 2001). Whiskeytown, located adjacent to the city of Redding, California, may also be receiving impacts. No air quality monitoring studies have been conducted within the park, but Air Atlas estimates from nearby monitors indicate that the park has high levels of ozone, which could impact vegetation in the park (more detailed information about Air Quality issues is included in Appendix H).

Climate change

Future climate change will have significant impacts for the Klamath Network region. Although there is uncertainty as to the exact timing and magnitude of future climate change, there is a growing scientific consensus that climate change is occurring and that human activities are contributing to this change (IPCC 2001). Estimates of global temperature increases for the next century range from 1.4° to 5.8° C, depending on the assumptions that are made about future greenhouse gas emissions, population growth, etc. (Albritton et al. 2001). For the western U.S., general circulation model (GCM) simulations of future climate indicate that temperatures will likely increase in both winter and summer (Giorgi et al. 2001). Precipitation is also simulated to increase in winter, with changes in summer precipitation being less certain. Thus, the Klamath Network region may experience warmer and wetter winters, and warmer summers in the future. Some modeling studies also suggest an increase in the strength of upwelling along the Pacific Coast of the Klamath Network region, which would help to maintain the coastal fogs that currently ameliorate coastal summer temperatures (Snyder et al. 2003). These fogs are considered important for maintaining appropriate climate conditions for the redwoods of Redwood National and State Parks.

The many different potential impacts of climate change have significant management implications for Klamath Network park units. Shifts in the distributions of species attributed to recent climate change have already been identified (e.g., Parmesan and Yohe 2003) and these shifts will continue in the future. Of particular significance to biotic communities is the potential loss of winter freezing temperatures in the Klamath Network region. Freezing temperatures control the distributions of a variety of plant and animal species. Loss of freezing temperatures would not only allow the expansion of certain native and non-native species in the region, but would also allow some insect pests to increase reproduction (Ayres and Lombardero 2000). Disturbance regimes, such as the frequency and magnitude of fire, will also be affected by climate change, with increased summer temperatures potentially increasing fire potential (Flannigan et al. 2000).

Climate change will also affect the hydrologic systems of the Klamath Network region. Combined changes in temperature and precipitation will alter the amount, seasonal timing, and duration of snowpacks and stream flows These alterations affect both water quality and quantity. Mote (2003) evaluated snow data for the Pacific Northwest and found a decrease in snow water equivalent (i.e., the depth of water equivalent to the weight of the snowpack) related to increases in temperature for the period 1950-2000. A number of studies have also simulated future changes in snowpack and runoff, which indicate future decreases in snow (e.g., Leung et al. 2004) and changes in the timing of snowmelt runoff (e.g., Stewart et al. 2004) for the Klamath Network region.

1.7. MONITORING IN THE KLAMATH NETWORK

A. Past and Present Monitoring

A comprehensive breakdown of monitoring that has been done and that is ongoing in the Network is provided in Appendix J. A brief summary is provided here. The National Park Service has ongoing monitoring programs in Air and Water Quality in the Klamath Parks (Appendixes F and H). Here, we provide short overviews of these two issues and relevant monitoring activities.

Air Quality

With the Clean Air Act (CAA), Congress established increased protections for 48 national park units designated as Class I areas along with additional measures to protect the remaining park units—Class II areas. The Klamath Network (KLMN) includes four Class I areas (Crater Lake NP, Lassen Volcanic NP, Lava Beds NM, and Redwood NP) and two Class II areas (Oregon Caves NM and Whiskeytown NRA). The majority of NPS air resources monitoring occurs in the Class I parks, while the Class II parks often obtain air quality data from cooperating agencies. The four Class I parks in the Klamath Network all have at least one type of air quality monitor within the park boundaries, but the two Class II parks (Oregon Caves NM and Whiskeytown NRA) have no within-park air quality monitoring stations. Lassen Volcanic NP has the most extensive air quality monitoring program in the network. The history of monitoring at each park unit can be found on the NPS Air Resources webpage:
http://www2.nature.nps.gov/air/Monitoring/MonHist/index.cfm. For park units without on-site monitoring, estimates of many air quality parameters can be found in Air Atlas at http://www2.nature.nps.gov/air/Maps/AirAtlas/index.htm.
More detailed information on air resources is contained in Appendix H.

Water Quality

In 2003-2004, the Klamath Network began summarizing years of data on water quality of the Klamath Parks (Appendix F). It is clear that some areas of the network (e.g. Crater Lake, and the Redwood Creek Watershed) have been the focus of intense scientific study for many years, whereas other areas (e.g. lakes at Lassen or the entire Redwood shoreline) have received comparably little study. It is also clear that there is much to be done in terms of basic inventory and establishment of baseline conditions for water quality monitoring. With funding from the NPS Water Resource Division, baseline inventories in Lava Beds, Lassen Volcanic, and Oregon Caves began in 2004 and will continue through 2005.

Outstanding Waters- There are no designated Outstanding Resource Waters (ORW) within the Klamath Network. However, the staff of both the Klamath Network and Crater Lake are in the process of petitioning the Oregon Department of Environmental Quality for ORW designation for Crater Lake.

Protection Areas- The North Coast Regional Water Quality Control Board has identified Redwood National Park as a State Water Quality Protection Area (SWQPA), designated by the California State Water Board.

Clean Water Act Section 303d Impaired- There are four listed 303d impaired waters within the Klamath Network. Two of these are located within Redwood (Redwood Creek and the Klamath River) as the result of adjacent upstream land use practices, in particular, the road building and reduced land cover associated with logging. There are two 303d waters in Whiskeytown: Willow Creek (associated with past mining activities) and the designated swim beaches.

The Klamath Network incorporated water quality scoping and issue identification into our overall vital signs scoping process. We held a separate workshop for marine issues and an aquatic working group within the network vital signs workshop. Consequently, our general monitoring questions and candidate vital signs address various elements of water quality along with more general concerns about aquatic ecosystems. In a similar way, we developed general conceptual models for marine and lentic and lotic freshwater ecosystems (see Chapter 2), but not specifically for water quality. These general models will be refined to address more specific water quality concerns in Phase II of the development of our general and water quality monitoring plans.

Other Agencies and Institutions

Federal Agencies. As in the rest of the western United States, the USDI Bureau of Land Management (BLM) and the USDA Forest Service act as the major administrators of non-NPS public lands around the parks. Major BLM programs in California with monitoring components that may be of particular interest to NPS are the noxious weeds, fire management, and special-status-plants programs. In Oregon, they include rangeland health; banding, inventory, and monitoring of northern spotted owls; and watershed-analysis programs.

USFS research stations employ scientists with a strong theoretical and often applied understanding of various aspects of forested ecosystems, who have administered a number of local research projects in the Klamath ecoregion. These projects have included manipulative experiments and longer-term studies of individual ecosystem components that may provide baseline data and science-based understanding. In addition, the Forest Information and Analysis program of the USFS maintains forest inventory plots in all the Network parks.

The Forest and Rangeland Ecosystem Science Center of the US Geological Survey boasts particular expertise in conservation genetics, invasive plants, scientific support for monitoring, herpetofauna, contaminants, wetland ecology, rangeland ecology, and biogeochemistry in the Klamath region.

The National Resource Conservation Service's mapping and surveys of soils will be valuable to units of the Klamath Network. The Snow Survey Program, which provides mountain-snowpack data and stream flow forecasts for the western United States, may also be used for water-supply management, flood control, climate modeling, recreation, and conservation-planning applications.

The Environmental Monitoring and Assessment Program (EMAP) is the Environmental Protection Agency's most significant monitoring effort. Its goal is to "build the scientific basis, and the local, state, and tribal capacity to monitor for status and trends in the condition of the Nation's aquatic ecosystems." Given that only 50 locations across the entire state of Oregon were sampled (and one or none of those was immediately near any NPS unit) on only one occasion (D. White, pers. comm), the value of EMAP for the Klamath Network may lie in its ability to design and modify protocols for multi-scale sampling of aquatic ecosystems.

The U.S. Fish and Wildlife Service (FWS) administers eight National Wildlife Refuges (NWRs) within the vicinity of the Klamath Network (five in California and three in Oregon). A FWS program of particular note for Inventory and Management efforts is the National Wetlands Inventory, the goal of which is to provide "current geospatially referenced information on the status, extent, characteristics and functions of wetland, riparian, deepwater and related aquatic habitats in priority areas to promote the understanding and conservation of these resources."

<u>State Agencies</u>. Oregon Department of Fisheries and Wildlife (ODFW) is the agency responsible for issuing licenses and regulations for game species, in accordance with the status and trends of those species. ODFW's stated mission is "to protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations." Past and present scientists and administrators at ODFW made significant contributions to a sourcebook volume on 593 wildlife species and their relationships with the 32 terrestrial, freshwater, and marine habitat types of Oregon and Washington (Johnson and O'Neil 2001). This sourcebook appears to hold great potential utility as the vital signs process matures.

The California Department of Fish and Game's (CDFG's) stated mission is "to manage California's diverse fish, wildlife, and plant resources, and the habitats upon which they depend, for their ecological values and for their use and enjoyment by the public." By law, the Department has responsibility for periodic monitoring of the state's diverse biological resources to assure their conservation for current and future residents. Monitoring involves not only assessing the status of individual species, but also the status of their habitats. The products produced by DFG appear to verify this commitment, as a search for “monitoring” from the Department’s main page produced a listing of 1,317 documents. Of particular interest for the Network is the Department’s Resource Assessment Program (California Department of Fish and Game 2001); available at http://www.dfg.ca.gov/habitats/rap/pdf/resassessprogram.pdf).

The California and Oregon State Parks systems (179 units in Oregon and over 270 units in California) are most similar to National Parks in their enabling legislation. Monitoring within the state park systems is usually performed to ensure the efficacy of a particular management action. Monitoring other than this is generally performed in collaboration with another agency or organization.

Other Organizations. Partners in Flight Breeding Bird Surveys, which involve workers and volunteers of varying levels of experience, occur extensively both in time and space. The Klamath Bird Observatory, based in Ashland, Oregon, conducts bird monitoring in Klamath Network parks and on private and federal lands throughout the region.

The Nature Conservancy's (TNC’s) stated mission is “to preserve the plants, animals and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive.” The TNC works to accomplish this goal by purchasing high-integrity landscapes or creating a diversity of conservation agreements (e.g., conservation easements) that balance human needs with long-term conservation of biological resources. A variety of monitoring may take place on these holdings.

B. Identification of Monitoring Concerns and Vital Signs

The identification of vital signs for monitoring ecological integrity of the Klamath Network Parks has entailed a number of steps and is an ongoing process. Individual vital signs scoping workshops were initially held for each Park unit prior to formal establishment of the Klamath Network (Appendix G). After the Network was established, three workshops were held in 2004, covering 1) the marine environment at Redwood, 2) the geology and soils, and 3) terrestrial, freshwater aquatic and subterranean ecosystems across the Network. The culmination of all of these efforts was the identification of numerous monitoring questions and associated potential vital signs. These were put into the National Vital Signs Framework and are presented, along with details about the workshops and scoping process, in Appendix G. A summary table of the most common monitoring questions and topics that were raised is presented, also using the national framework categories (Table 1.7). Additional monitoring questions and potential vital signs may be considered during the Phase II planning and prioritization process. In addition, ongoing monitoring, as summarized in the previous section, must be evaluated to determine which monitoring questions can be answered adequately by other entities.

Table 1.7. Most commonly identified monitoring questions or topics and their associated vital signs in the Klamath Network vital signs identification process.

National Framework		Monitoring Question or Topic	Potential Vital Sign
Level 1	Level 2		
Air and Climate	Air	What are status and trends in wet/dry deposition? What are status and trends in atmospheric pollutants?	Deposition, S & N, particulates (see Appendices F and H)
			Pollution (see Appendix G)
			Sensitive species (amphibians lichens, plants)
			Snow Chemistry
		What are status and trends in visibility (incl. Light pollution)?	Visibility, Light Pollution
	Weather/ climate	What is timing and duration of key phenological events?	Key phenological events (as yet undetermined).
		Are climate associated ecotones changing through time (treeline, other vegetation types)?	Ecotones, (e.g. timberline)
		How do ENSO and climate change affect marine and terrestrial organisms?	Many organisms proposed (see Appendix G)
		Are fog dynamics (amount, inland penetration, etc.) changing?	Fog dynamics (Redwood NP)
		How is sea level changing?	Sea level, Intertidal organisms
		Are ocean temperatures changing?	Sea surface temperature
Geology and Soils	Geomorphology	Have rates, extent, location, or types of erosional and depositional processes changed?	Erosion and deposition processes (see Appendix)
		How is coastal morphology changing?	Nearshore/shoreline processes
	Subsurface processes	See water quality	
	Soil quality	Are we losing topsoil?	Soil integrity (need specifics)
		How is soil fertility changing?	Soil fertility

National Framework		Monitoring Question or Topic	Potential Vital Sign
Water	Hydrology	What is the effusion rate of groundwater into the surface environment? (geothermal)	Groundwater dynamics (geothermal discharge)
		What are ground water changes?	Aquifers (depth volume variability)
	Water Quality	How are changes in water and ice quantity, rates, and quality affecting cave/lava tube erosion, deposition, and biota?	Subterranean (cave, lava tube) water/ice quantity and quality
		What are status and trends in point source pollution?	Point source pollutants (oil and plastic materials in marine environments).
			Seabirds, marine mammals.
		What are status and trends in non point source pollution?	Non-point source pollutants
		What are status and trends in permanent and ephemeral aquatic communities?	Aquatic organisms (macroinverts., fish, amphibs.)
		What are the status and trends in turbidity (marine/estuary)?	Turbidity
Biological Integrity	Invasive species	How are invasive species affecting aquatic and terrestrial ecosystem processes?	Fuels and fire
			Water levels
		How are invasive species affecting aquatic and terrestrial ecosystem species' abundance and composition?	Species composition and relative abundance
		How are invasive species abundance, composition, and distribution changing?	Invasive species
	Infestations and Disease	What are parasite/pathogen trends in terrestrial and marine systems (especially non-native pathogens)?	Parasites/pathogens, especially non-native
	Focal Species or Communities	What are long term trends, abundance, distribution, demographics especially productivity, of focal species/ communities? What are wildlife and plant demographic trends in focal species?	Riparian communities
			Whitebark pine forests
			Redwood forests
			Old growth forests
			Butterflies
			Landbirds

National Framework		Monitoring Question or Topic	Potential Vital Sign
			Waterbirds
			Biocontrol insects
			Small mammal communities
			Herpetofauna
			Large carnivores, megafauna, megaflora
			Habitat specialists/obligates
			Pika metapopulations
			Ungulates
			Bryophytes
			Lichens
			Pollinators (invert. and vert.)
			Rare species
			Invertebrates/algae communities and/or populations
			Common Murre colonies
			Marine mammals
			Bull kelp
Human Use	Point Source Effects	What are status and trends in Fishing boats/lights, flyovers, and snowmobile use (large machines affecting parks)?	Machine use in or near parks
			Wildlife migration
			Marine mammal/seabird disruption
		What are effects of mining, geothermal exploration and development?	Water quality, bioaccumulation
	Non-point Source Effects	What are the trends and effects due to illegal harvesting of park resources (e.g. elk, mushrooms, plants, herps, forest products, salmonids), including commercial fishing in adjacent waters?	All items listed in this monitoring question
	Visitor Use	What are trends in visitor and recreation use?	Visitor and recreation use

National Framework		Monitoring Question or Topic	Potential Vital Sign
		What are status and trends in watercraft use?	Marine mammal and sea bird behavior
		What are status and trends in sensitive habitat use?	Tide-pools, caves
Ecosystem Pattern and Process	Disturbance	What are the natural disturbance regimes and how are they changing over time and what is the ecological response?	Fire and other landscape scale disturbances
	Land use and cover	How is land use and land cover changing in and around parks?	Land cover/use, roads
		What is the connectivity of old growth forests?	Forest fragmentation and affected wildlife
		What are status and trends of woody debris?	Woody debris, snags
		How is the riparian community changing?	Channel morphology
			Woody debris
			Plant and animal composition

CHAPTER TWO: CONCEPTUAL ECOLOGICAL MODELS

2.1. INTRODUCTION

Service-wide guidelines for establishing Inventory and Monitoring Network Vital Signs Monitoring programs in the National Parks call for the development of conceptual models that "provide a summary of the understanding of the park ecosystem." The conceptual models and the process of developing them are considered key steps meant to improve understanding of and communication about complex systems and to assist in designing a vital signs monitoring program (Gross 2003). Conceptual models can also help provide consistent principles around which the vital signs report can be organized.

A conceptual model is a visual or narrative summary that illustrates the important components of the ecosystem and the interactions among them. Effective conceptual models help scientists convey complex principles with impact and economy, and promote integration and communication among scientists and managers from different disciplines. Development of conceptual models also helps the designers of a monitoring program better understand how the many components of ecological systems interact. This chapter describes the Klamath Network process for developing conceptual models to guide the vital signs monitoring plan. The goal of these conceptual models is to explain our understanding of the drivers of change in Park ecosystems so that the vitality of these systems can be monitored.

2.2. A CONCEPTUAL BASIS FOR MONITORING IN THE KLAMATH NETWORK

Monitoring can inform many areas of land management, providing practical details relevant to park operations as well as critical information for the conservation of biological diversity (Noon et al. 1999, Busch and Trexler 2002). The need for a conceptually sound and quantitative basis for gauging the status and trends of park ecosystems has been proposed by numerous internal and external reviews of the National Park Service policies and actions (National Academy of Sciences 1992, reviewed in Sellars 1997, and Appendix B). This chapter of our report aims to communicate such a conceptual foundation for identifying vital signs of the ecosystems of the Klamath Network.

A. Ecosystem Structure, Composition, and Function

Franklin et al. (1981) recognized three primary characteristics of ecosystems: composition, structure, and function. These can be used to assess the ecological integrity of Park ecosystems. *Composition* is the array of ecosystem components (genes, species, populations, special habitats, and so on.). *Structure* refers to the spatial arrangement of physical components, such as canopy structure, or the arrays of corridors for species movement. *Function* refers to the many processes that ecosystems require and provide through time, such as nutrient cycling, carbon cycling, hydrologic cycling, etc. Noss (1990) modified this classification to describe potential indicators of biodiversity and created a conceptual model illustrating how composition, structure, and function might be expressed across a hierarchy of spatial scales and biological organization (Figure 2.1).

In the Klamath Network parks, the Park Service stewards globally recognized biodiversity with exceptional levels of species richness, endemism, and rarity (DellaSala et al. 1999, Section 1.4). A major management challenge is to maintain this biodiversity through time. The three-part framework describes fundamental dimensions of the system at all scales. It therefore provides a comprehensive framework for identifying the vital signs of a biophysical system (Chapter 3).

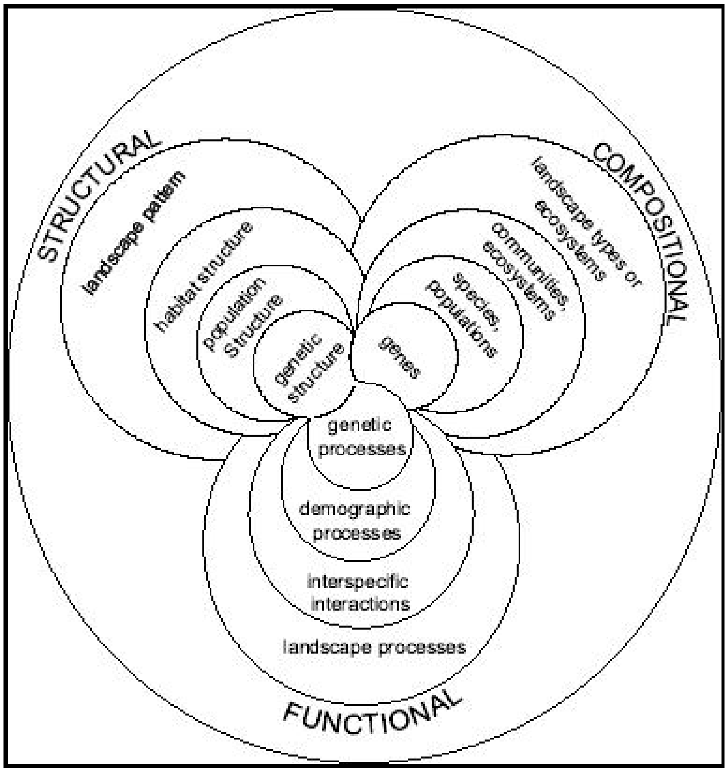


Figure 2.1. Conceptual model illustrating multi-scale hierarchy of biodiversity indicators that describe composition, structure, and function at each level of scale and biological organization (from Noss 1990).

B. Multiscale and Multispecies Integration

A monitoring program must also have an approach to measuring park phenomena and relevant issues that spans multiple spatial scales. A growing body of ecological literature illustrates that the relative importance of different controls on species abundance and diversity varies across spatial and temporal scales (Holling 1992, Whittaker et al. 2001, Bestelmeyer et al. 2003, Sarr et al. 2005). Therefore, monitoring must provide information across the range of spatial and temporal scales that is relevant for the organisms present.

Assessment of human impacts also requires a multi-scale perspective and a corresponding diversity in sampling approaches. Impacts to specific habitats may require more focused attention than is likely to occur in a park or network-wide sampling grid. The impact of larger scale influences, such as effects of climate change, will require partnership and information sharing with regional, national, or international partners.

Monitoring must also effectively integrate information across species, life forms, and ecosystems. Approaches that monitor the status and trends in structure and variation of biota in terms of gradients on three levels (environmental factors, species populations, and characteristics of communities (Whittaker 1967)) may be needed to determine trends in ecological integrity of Park ecosystems. Such approaches place greater emphasis on the kinds and degrees of relationships among different organisms in a community than more taxon specific approaches. In particular, we suggest that monitoring multiple species or attributes together may track changes in ecosystem structure, function and composition better than single entities. Gradients upon which to sample biotic assemblages may be apparent, and many are shown in the conceptual models presented in this chapter. In addition, multivariate approaches for the comparison of samples may also cause gradient relationships to emerge from the data. How these relationships change over time may be a vital sign of ecosystem integrity.

2.2. Conceptual Model Development

The conceptual modeling process in the Klamath Network involved review of relevant literature within and outside the National Park Service, active discussion among the Klamath Network staff, consultation with scientific staff at the National Inventory and Monitoring office, and solicitation of comments on draft models in several scoping meetings (see Appendix G). The Klamath Network approach to conceptual models first involved a survey of models that were prepared by other networks. We identified two basic strategies for modeling complex systems that are affected by human activities: 1) incorporate effects of humans directly from the outset (stressor-based models); and 2) develop models based on a biophysical understanding of the system without human impacts (ecosystem-process models) first, and then incorporate human impacts. We chose the latter approach initially.

We first considered developing conceptual models for each major ecosystem type in the network, but dismissed that approach when it became apparent that it would produce a large, and redundant family of conceptual models. Rather than approach the ecosystems as discrete pieces, we chose to portray them as broader ecosystem domains (marine, freshwater aquatic, terrestrial, and subterranean), structured into ecological zones by environmental gradients. We also grappled with the issue of finding consistent levels of detail in the various conceptual models. We addressed this problem by constructing a hierarchical family of models that range from broad and comprehensive to focused and detailed. This approach provides general models for communication with non-scientists, yet it allows us to construct submodels with as much detail as needed for a particular problem or a highly specialized audience.

Of the conceptual models we reviewed, we were particularly impressed with those recently prepared by the Southwest Alaska Network (SWAN) (Bennett et al. 2003). Their models were hierarchical, visually appealing, interesting, and covered a suite of broad concepts. In their Phase 1 Report, SWAN introduced the concept of a holistic conceptual model, with submodels describing more specific elements in greater detail. We incorporated three major organizing features and design elements from the SWAN conceptual models: 1) the use of the hierarchical structure employing one holistic model with a family of submodels, 2) a broad classification of park ecosystems (e.g., marine, freshwater aquatic, terrestrial, and subterranean), and 3) an attempt to create evocative, visually-engaging models.

As we developed our models, we worked from the general to specific. We began by considering the primary environmental influences on ecosystem structure, composition, and function in the Klamath Network parks. The holistic conceptual model is a simple diagram portraying these influences. Submodels were simply components of the holistic model (ecosystems or major influences) expanded into greater detail. The hierarchical, nested set of models developed for the Klamath Network includes: 1) a holistic conceptual model of ecosystem domains showing the major influences on park ecosystems and 2) submodels of park ecosystems, illustrating the influences in greater detail.

2.3. CONCEPTUAL MODELS

A. A Holistic Conceptual Model of Influences on Klamath Park Ecosystems

Our initial Holistic Conceptual Model described the major abiotic, biotic, dynamic, and historic dimensions of the environment and the driving forces shaping park ecosystems and the landscapes in which they occur. These factors determine the structure, function, and composition of park ecosystems. Human influences were originally thought to impinge upon this biophysical system from outside. After discussion with park staff, we removed historic influences and moved human influences within the holistic model, making explicit our view that humans are an integrated part of the biophysical environments in the Klamath Network parks. We then divided park ecosystems into four major domains: marine, freshwater aquatic, terrestrial, and subterranean. It was not our intent to use a definitive ecosystem classification for the model. Rather, we wished to portray four major domains that were intuitive and that will allow later subdivision, as needed. To spur our thinking in the vital signs workshop, we encouraged participants to consider the effects of major influences on ecosystem *structure*, *composition*, and *function*. The final Holistic Conceptual Model is the outcome of these discussions (Figure 2.5).

In the following section, we provide a short justification for each of the major components of the Holistic Conceptual Model. We then present conceptual submodels illustrating the influence of each major component in the park ecosystem domains. This results in three sets of conceptual submodels: 1) models of ecological zonation along gradients, (2) models of natural ecosystem dynamics, and (3) models of human-caused influences on ecosystem dynamics.

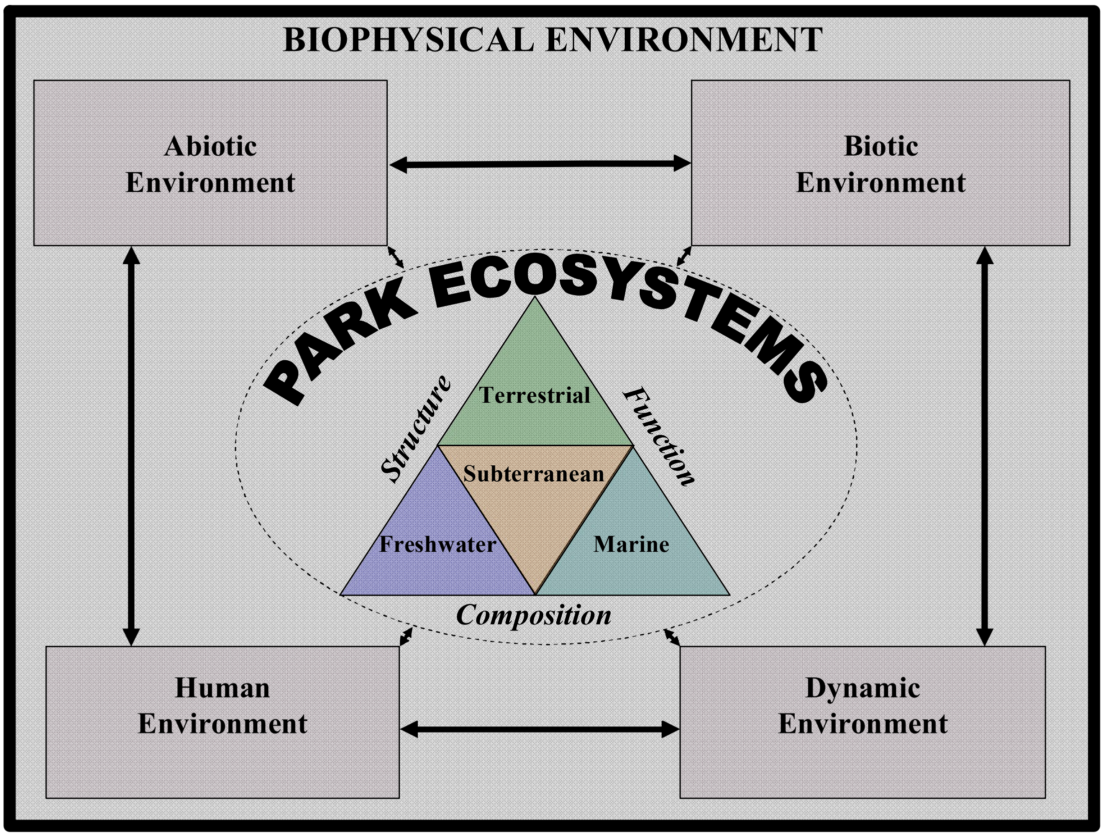


Figure 2.2. A Holistic Conceptual Model of influences on Klamath Park Ecosystems.

B. Assumptions and Approach to Submodels

Gradient Models

The Klamath Region shows great geographic complexity. Much of this variation arises from ecological zonation across the steep abiotic gradients that characterize the region. Because the landscape gradients in the Klamath Region are so pronounced (Whittaker 1960), and are such strong drivers of ecosystem patterns and processes, we assumed that this gradient structure would provide an ideal background upon which to conceptually portray biotic variation across the terrestrial landscape. There are also strong gradients and pronounced zonation in marine and freshwater ecosystems, underscoring the generality of the gradient model approach.

Zonation has long been recognized in terrestrial ecosystems (Merriam and Steineger 1890) and is clearly evident in aquatic and wetland ecosystems as well (Ricketts and Calvin 1939, Vannote et al. 1980, Mitsch and Gosselink 2000). We employ the zonation concept in the first set of ecosystem submodels for practical reasons. First, the striking nature of spatial patterns of the Klamath Region suggests that they can be linked to known biophysical drivers such as climate, geology, and wave action, which form the most fundamental controls on ecosystem processes and the living organisms they support. Second, the number of individual ecosystem types in the Klamath Network has never been determined, and it would likely yield too many systems to describe in this report, with many of the ecosystems largely redundant in gradients or dynamics. Finally, the gradient models are fairly simple and straightforward so that they may be more engaging.

Dynamic Models

A wide range of disturbance processes structure the aquatic, terrestrial, and subterranean ecosystems of the Klamath Network parks. Landscape disturbances are highly variable and should probably be viewed as frequency distributions with general statistical properties, such as mean sizes, recurrence intervals, and intensities, but with a characteristic range in these properties. Disturbance dynamics are fundamental to the function of ecosystems and the diversity of life they contain. Our conceptual models illustrate the major dynamic processes structuring each of the major ecosystem types and the ecological zones within them.

The Human Effects Models

Although our Holistic Conceptual Model clearly includes humans as part of the biophysical environment of the Klamath Parks, we developed a series of human effects models for each major ecosystem to explore how human stressors can impact park ecosystems. We portray these relationships in one overview model and several submodels. All the models distinguish far-field influences that propagate across entire landscapes (e.g., air pollution, climate change, fire suppression) from near-field influences that cause more local, but potentially cumulative impacts (e.g., visitor use impacts, local disturbances, point source pollution). In the submodels, we portray the major human influences, the intermediate linking mechanisms or processes (e.g., abiotic and biotic gradients, ecosystem processes) that drive ecosystem structure, function, and composition, and several focal elements of recognized value to the parks.

C. Major Ecosystem Domains of the Klamath Network

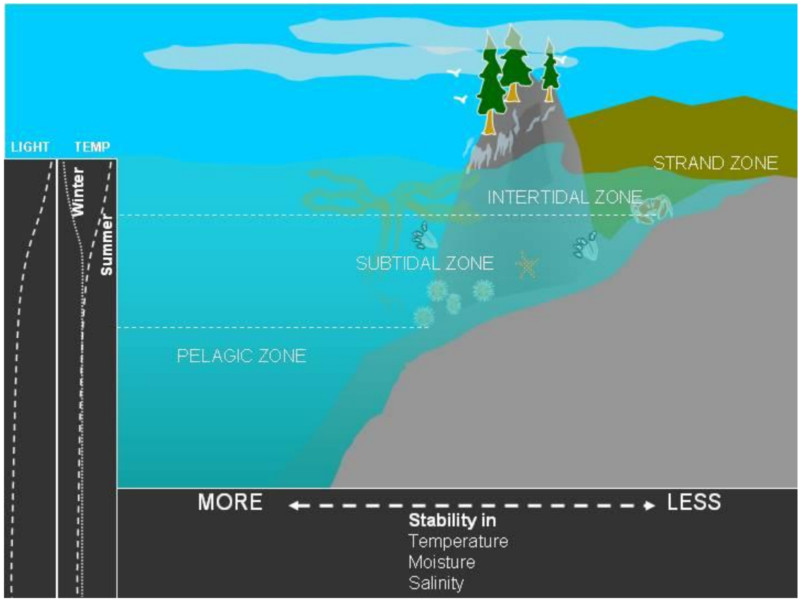
In this subsection, we outline the major ecosystem domains of the Klamath Network parks. In each case, we discuss the fundamental gradients that shape the biophysical environment, then discuss natural (intrinsic) ecosystem dynamics.

Marine Ecosystems

Near-shore marine environments have some of the sharpest zonation known and described in ecology (Ricketts and Calvin 1939, Bakker 1971). Along the gradient from dry sand to deep water, there are several major zones. All classifications of nearshore ecosystems recognize the sharp decline in the variability of the environment, in the duration of desiccation, and in light availability. Ricketts and Calvin (1939) also emphasized the importance of wave shock as a fundamental control on the richness and distribution of coastal organisms. The substratum type complicates these gradients of environmental conditions, with rocky and sandy substrates creating relatively distinct living environments. A conceptual model of the marine environment (Figure 2.3) illustrates the gradients in stability and changes in abiotic conditions with depth.

Across the ecological zones from strand to sea, there are important changes in ecosystem dynamics, especially the type and intensity of disturbance (Figure 2.4). Near the shoreline, wave action is a constant force shaping species distributions. Storm waves occur each year, but especially powerful storm waves can strongly influence the intertidal zone. These disturbances can be particularly forceful when aided by driftwood or other debris. Extreme tides can also form disturbances through atypically long periods of inundation or desiccation. Along the northern California coast, tsunamis have occurred periodically, driven by tectonic events that may happen far away, the latest being the famous wave of 1964 that was a natural disaster in the nearby town of Crescent City. Farther from the shoreline, larger scale marine processes, such as upwelling, longshore currents, and seasonal and interannual oscillations in ocean temperatures become primary controls on the distribution and abundance of organisms.

a.



b.

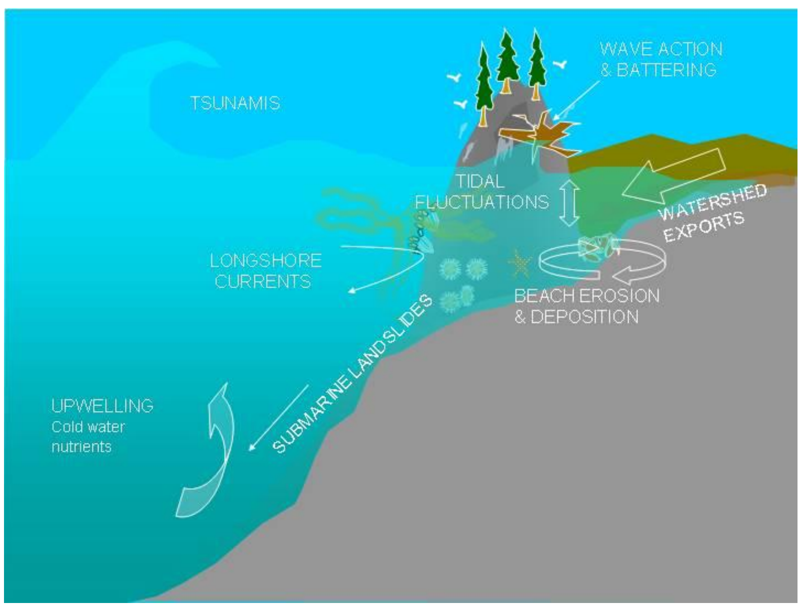
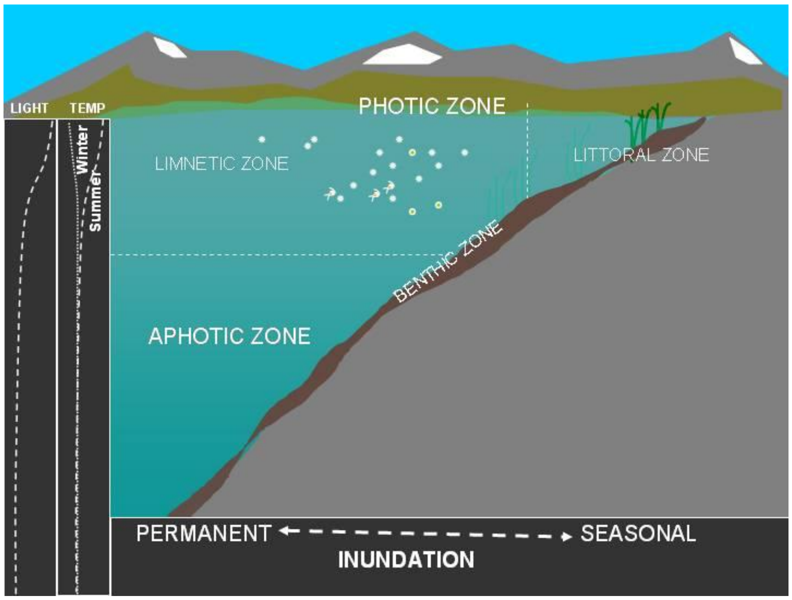


Figure 2.3 a, b. Conceptual model of marine ecosystems, showing a.) major abiotic gradients and ecological zonation (changes in abiotic conditions with increasing depth are portrayed in vertical line graphs), b.) major dynamic processes.

Freshwater Ecosystems

Zonation of lakes is similar to the coastal environment in many ways. The primary gradient in lakes is from the wave-influenced, well-illuminated, and seasonally variable littoral zone to the comparatively stable, but light-poor depths (Figure 2.5). The depth of the lake and nature of the shoreline also strongly influence the attributes of the water column and the organisms present. Shallow lakes, such as many in Lassen, have well developed littoral zones with high productivity, extensive wetland development, and tight coupling to the surrounding terrestrial environment. In deeper lakes, such as Crater Lake, open water (pelagic) processes are most important, and productivity is much lower with a very large aphotic (no light penetration) zone.

a.



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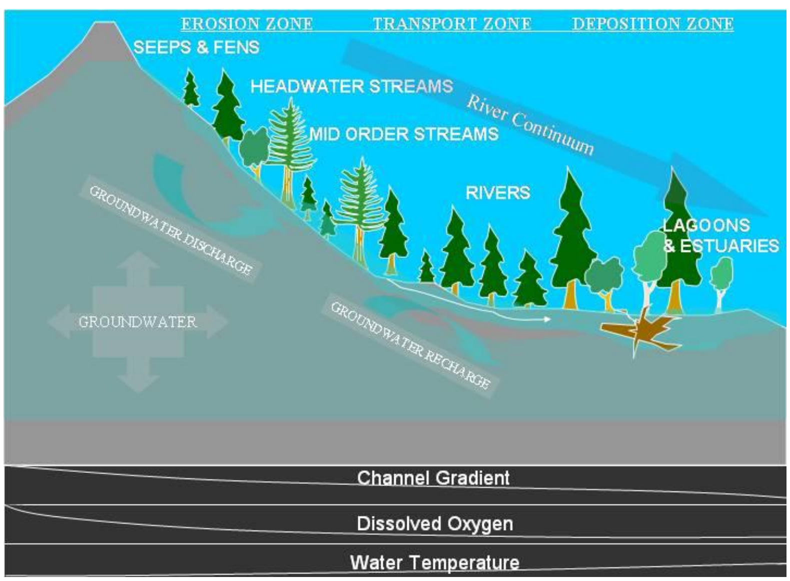
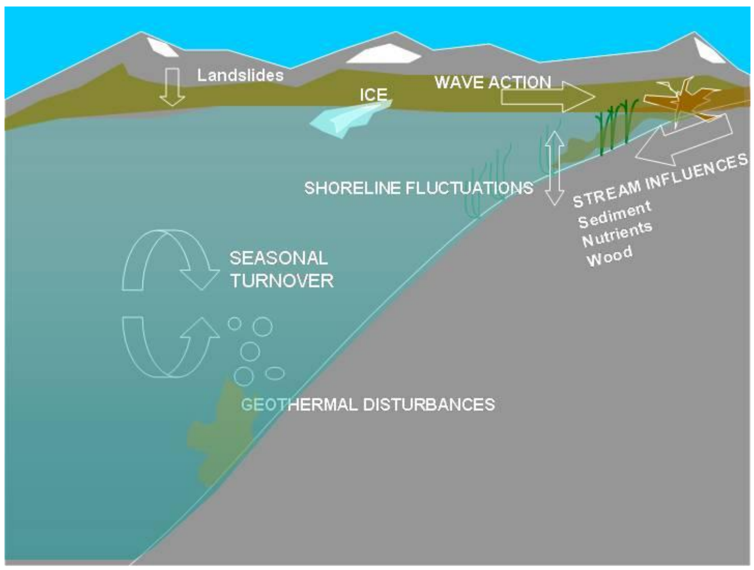


Figure 2.4 a, b. Conceptual model of freshwater ecosystems, showing a.) major abiotic gradients and ecological zonation in lake (lentic) ecosystems, b.) major abiotic gradients in flowing freshwater (lotic) ecosystems showing changes in the channel gradient, dissolved oxygen, and water temperature down the stream. The river continuum refers to the abiotic and biotic changes from headwaters to larger streams (Vannote et al. 1980).

Flowing water (lotic) ecosystems change predictably from headwaters to downstream. The river continuum (Vannote et al. 1980) is an excellent depiction of this pattern that is well expressed in running water environments of the Klamath Network parks (Figure 2.6). Along the river continuum from headwaters to lowland rivers, there are typically predictable increases in water temperature, declines in dissolved oxygen, decreases in average substrates size, and increases in the proportion of within-stream (autochthonous) production of carbon. These abiotic changes drive changes in aquatic biotic composition along the same gradient.

a.



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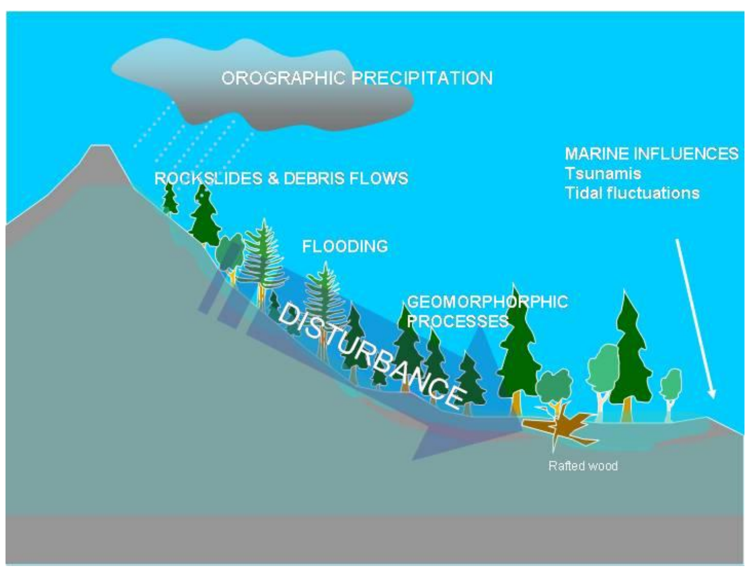


Figure 2.5 a, b. Conceptual model of major dynamic processes in freshwater ecosystems: a.) lake (lentic) ecosystems, b.) flowing freshwater (lotic) ecosystems.

The dynamics of freshwater ecosystems show variation across the major ecological gradients. From the littoral to pelagic zones, major ecological dynamics in lakes shift from wave dynamics and effects of landscape disturbances to seasonal and interannual currents that mix the water column (Figure 2.7). Although they are quite dynamic ecosystems, relatively less of the spatial and temporal variation in lakes fits the definition of disturbance provided by Pickett and White (1985). Seasonal fluctuations in temperature, such as fall turnover, are essentially regenerative processes. So too are the sequential blooms of phytoplankton and zooplankton that drive seasonal shifts in water clarity and nutrient availability. The effects of more-typical disturbances, such as ice movement, wave action, and watershed influences, such as floods and debris flows, are less well understood in the lakes and reservoirs.

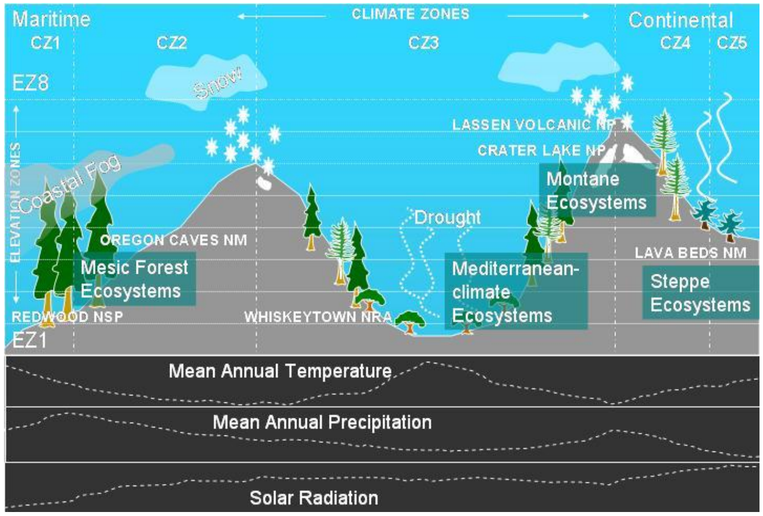
In contrast to lakes, stream ecosystems are particularly dynamic, with stochastic disturbances being primary organizing processes. A host of factors from within and outside the water column can disturb the stream and its riparian corridor (Figure 2.8), including debris flows, floods, and other geomorphic processes such as channel migration. Although initial conservation efforts sought to minimize deleterious disturbances to streams, an emerging paradigm (Reeves et al. 1995) proposes that an understanding of watershed and stream disturbances is fundamental to understanding the integrity of these ecosystems.

Terrestrial Ecosystems

The Klamath Network parks encompass landscapes with steep climate gradients associated with proximity to the Pacific Ocean. The decreasing maritime influence from west to east is associated with declines in precipitation, greater ranges in daily and annual temperature, and increases in solar radiation (Figure 2.9). A preliminary landscape classification for the region (Sarr et al. 2003) recognizes five climate zones and eight elevation zones. Temperatures decline with elevation in all climate zones, with deeps snows accumulating above approximately 2,000 m elevation. The coastal climate zone shows a sharp temperature inversion in summer, associated with coastal fogs, so that areas lower than 500 m in elevation are much cooler than corresponding areas in the interior. This unique fog belt strongly coincides with the distribution of coast redwood and the southern extension of many plant species from the Pacific Northwest. Together, the stark abiotic changes in ambient climate and elevation across the network are mirrored in a great variety of vegetation types.

In terrestrial ecosystems, landscape dynamics also show important variation across the region (Figure 2.10). Whereas windthrow is a relatively important disturbance in the storm-battered coastal forests, fire is the preeminent landscape-scale disturbance in nearly all the noncoastal sites (Franklin and Dyrness 1988). The frequency and severity of fire show both temporal and spatial variability, with the frequency of fire generally increasing from west to east and from high to low elevations (see Appendix D). Other, finer-scale disturbances, such as local root rot infestations, insect outbreaks, and landslides, are also found in unique vegetation types and topographic positions.

a.



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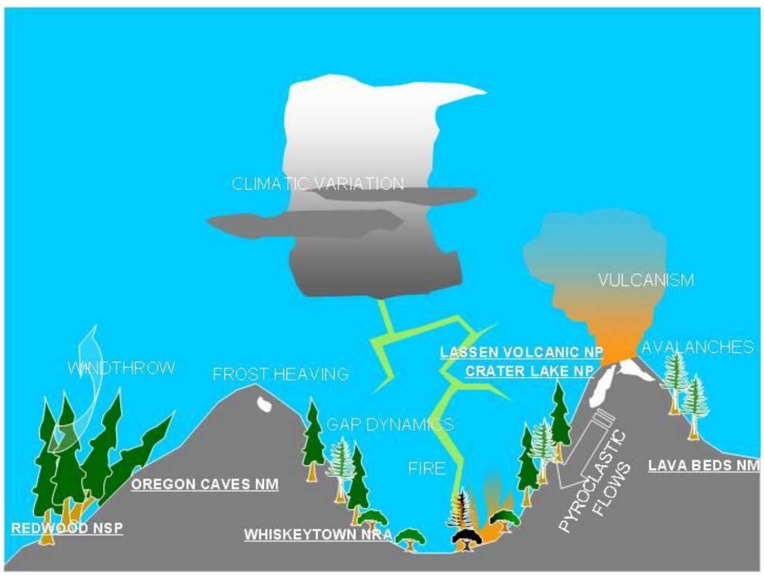


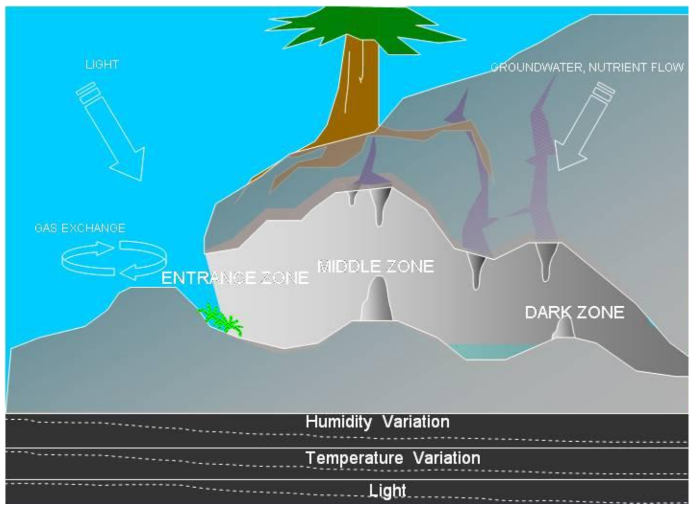
Figure 2.6 a, b. Conceptual models of terrestrial ecosystems, showing: a.) major abiotic and ecological zonation (Variation in several major ecological parameters is portrayed in horizontal line graphs. Elevation and climate zones are from a draft landscape classification that breaks the region into five climate zones and eight elevation zones.). b.) major dynamic processes.

Subterranean Ecosystems

The caves of the Klamath Network parks are spatially structured habitats with clear gradients in light, humidity, air flow, and air chemistry from the cave mouths inward (Figure 2.11). In general, the variability in the environment declines with increasing distance into the cave as the cave interior becomes decoupled from daily climate fluctuations. The unique, cool microclimates near cave mouths are known to be important for a number of plant and animal species occurring in Lava Beds National Monument. Such patterns probably also occur in the karst cave system of Oregon Caves.

Although they often occur slowly, cave processes are fundamental to the development and structure of the cave environment. Groundwater flow, and associated processes of mineral dissolution and accretion, create and maintain karst features. Similarly, seepage and freezing of water are necessary for the formation of ice caves, as are the summer temperature inversions that maintain them.

a.



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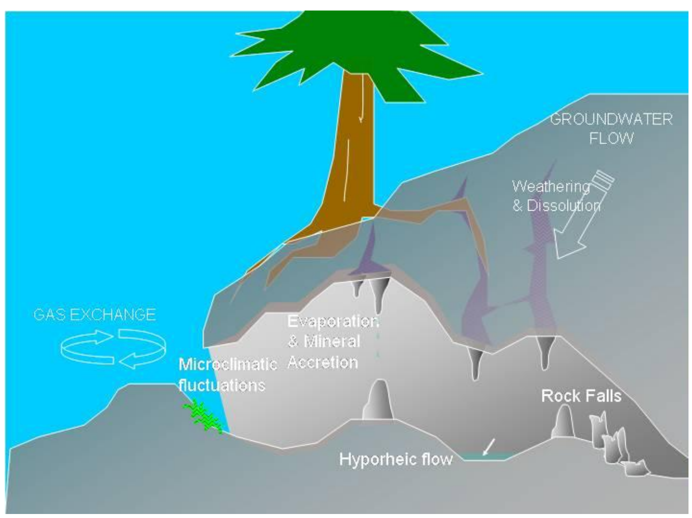


Figure 2.7 a, b. Conceptual models of subterranean ecosystems, showing: a.) major abiotic gradients and zonation (Variation in conditions is portrayed in horizontal line graphs). b.) major system dynamics.

Caves appear to be quite stable environments when compared with surface ecosystems, often showing remarkable consistency in temperature and humidity from day to day and year to year. However, disturbances caused by rock falls or the flooding of subterranean streams do provide some temporal variability. As one moves closer to the cave mouth, environmental conditions become more variable and may be affected directly or indirectly by surface disturbances (Figure 2.12). Viewed on longer time scales, caves ecosystems are highly dynamic, depending upon ongoing hydrogeologic and atmospheric processes.

D. Human Influences on Park Ecosystems

Humans have been elements of the Klamath Network park ecosystems for millennia. Their influences have changed dramatically over that time, with changes in technology, culture, and population densities. Although large parts of several of the parks in the Klamath Network are considered wilderness, the majority of most parks are, in fact, human-dominated ecosystems (Vitousek et al. 1997), and they will continue to be for the foreseeable future.

Although we recognize that not all human effects on ecosystems are detrimental, we feel it is valuable to analyze the stresses that are likely to occur they often have detrimental effects. A central goal of the long-term monitoring program is to detect changes that we suspect are caused by human actions. Potential sources of harm can come from near-field activities, such as campgrounds, local management actions, or point-source pollution, or from far-field effects, such as off-site pollution, climate change, and introductions of non-native species, that affect all the park ecosystems. Together, these stressors can affect the structure, function, and composition of park ecosystems, endangering their diversity and integrity (Figure 2.13).

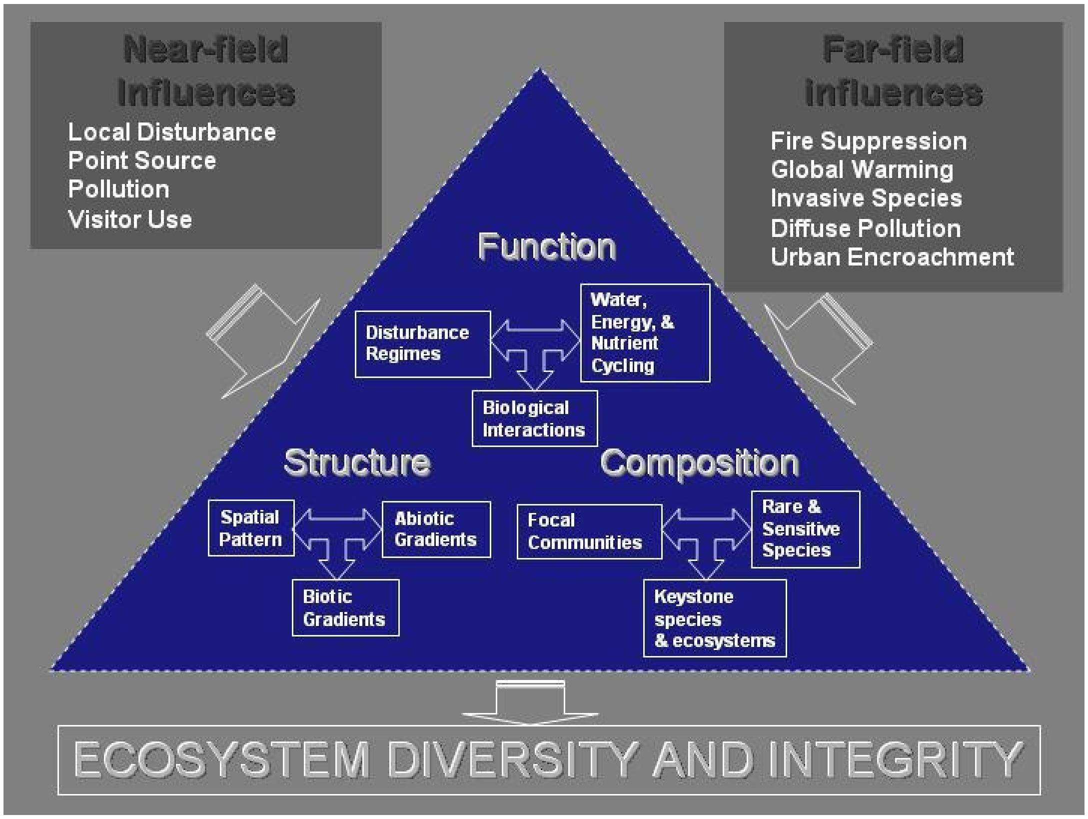


Figure 2.8. Human influences on the structure, function, and composition of park ecosystems.

Human influences on the marine environments of the Klamath Network include far-field factors, such as deepwater fishing, pollution, and disturbance to marine mammals and shorebirds by watercraft and aircraft. Human influences also include local effects of beach recreation, beachcombing, and rock climbing on sea stacks and coastal headlands (Figure 2.14). In addition, material trash (primarily plastic) has become abundant in marine systems. These factors influence the gradients and processes that maintain habitat for focal, keystone, and rare and sensitive coastal species.

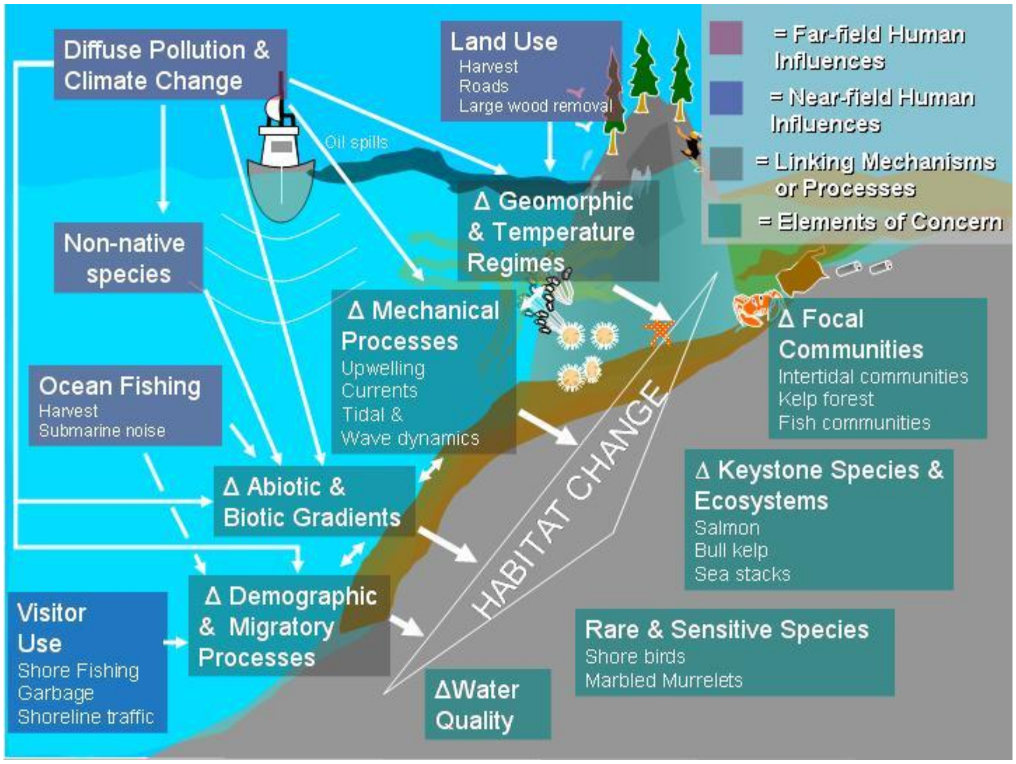
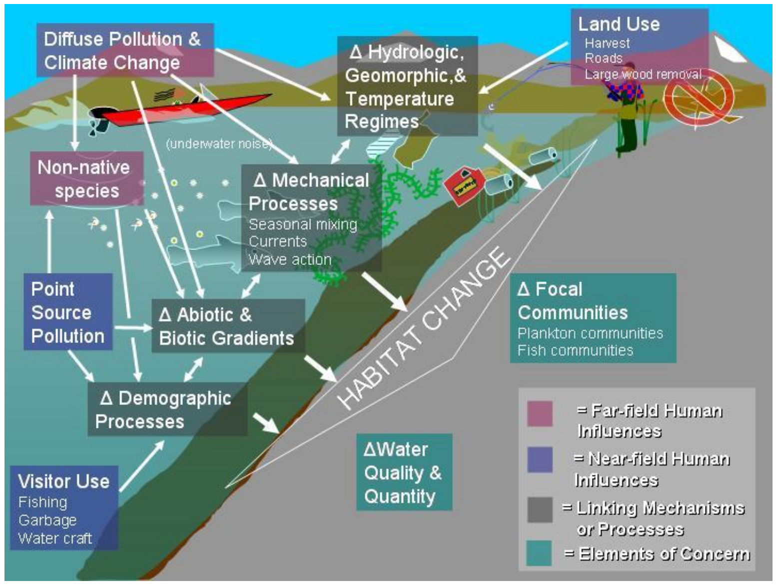


Figure 2.9. Conceptual model of human influences on marine ecosystems.

Recreational use of lakes in the network is a dominant influence and management objective in all the parks of the Klamath Network (Figure 2.15, 2.16). This is especially the case in Whiskeytown, where summer use of mechanized water craft can be nearly constant. Major activities along lakes and streams in the network include boating, water skiing, swimming, and fishing. Nearly all these uses have the potential to impact some elements of the aquatic ecosystem. Other major influences include effects of air and water pollution of local diffuse and point source origin, non-native plant and animal species, and surrounding land use. These factors influence the major mechanisms and processes of the lake ecosystems and affect both water quality and aquatic communities.

a.



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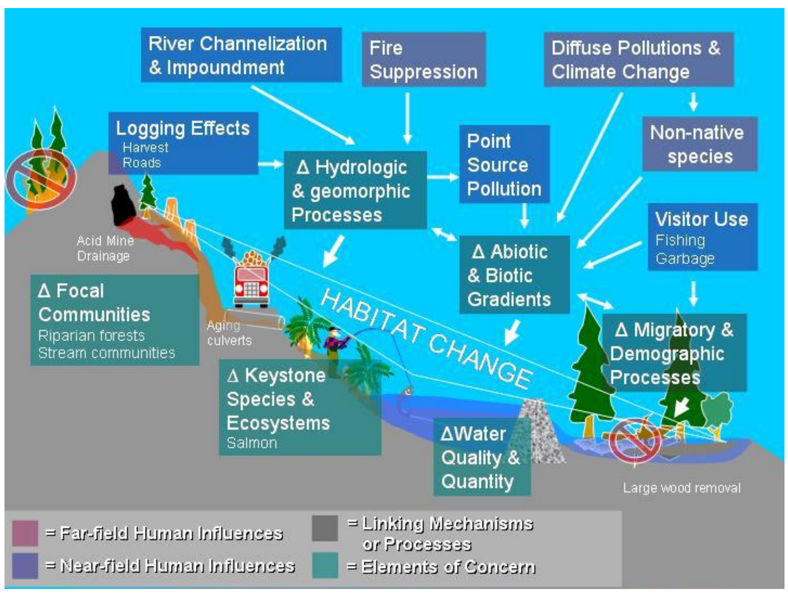

Figure 2.10. Conceptual model of human influences on freshwater ecosystems: a.) lake (lentic) ecosystems, b.) flowing water (lotic) ecosystems.

The stream ecosystems of the Klamath parks are particularly vulnerable to human effects throughout the watersheds in which they occur. Diffuse and point source pollution, fire suppression effects on hydrology, and human demands for water all strongly affect the stream and its residents. Stream and riparian environments are also known to be particularly vulnerable to invasion by non-native species (DeFerrari and Naiman 1994). Collectively, these threats influence the gradients and processes that maintain riparian habitat and stream fish communities, as well as water quality for human uses downstream.

Threats to terrestrial ecosystems range from local effects of visitor use on individual species and ecosystems (including the effects of campground and trail development and pack stock use), to more widespread and diffuse effects, such as the introduction of non-native plant and animal species (Figure 2.17). Although fire exclusion is commonly viewed as a major stressor of terrestrial ecosystems, the broader issue of fire and fuels management has potentially far-ranging effects on terrestrial environments in all the parks. These influences affect the structure of the habitat template, particularly the environmental gradients, disturbance regimes, and landscape patterns that create habitat for ecosystems, communities, and species of interest, such as major plant communities (e.g., redwood forest), keystone ecosystems such as aspen and whitebark pine stands, and potentially imperiled groups such as amphibians and rare plant species.

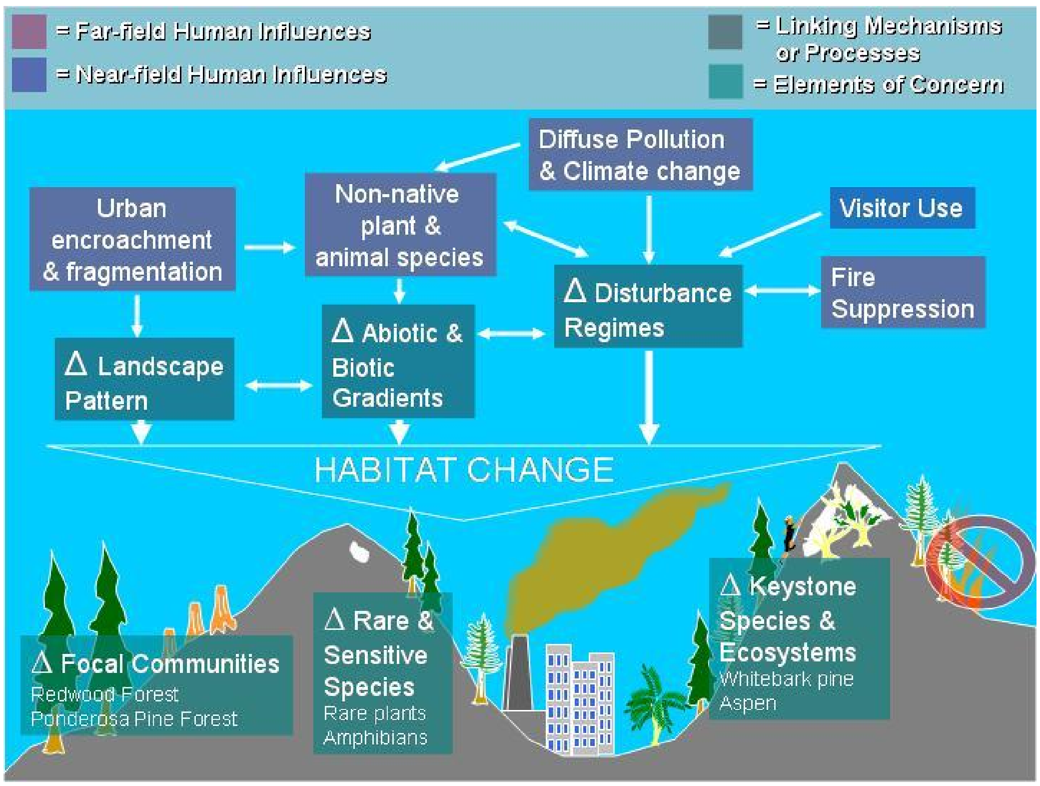

Figure 2.11. Human influences on terrestrial ecosystems.

Human influences on the subterranean environment include effects of excessive visitor use on cave biota through off-trail travel, nutrient enrichment through addition of lint or food crumbs, touching of sensitive geological formations, and disruption of bat hibernacula (2.18). Changes in microclimate caused by excavation of new passageways or development of visitor facilities are also believed to be potentially harmful. Fire suppression may also be a threat to Oregon Caves because the increased growth of vegetation may affect cave water balance. In addition, far-field influences, such as climate change and pollution may affect the intricate balance of chemical and atmospheric processes that foster the growth of cave formations.

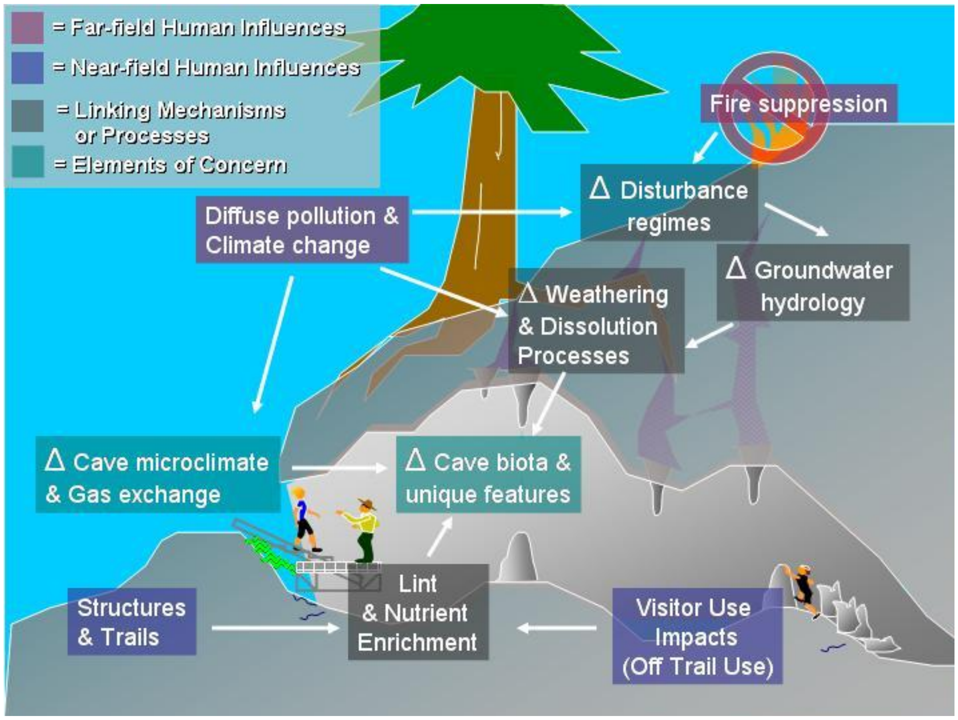

Figure 2.12. Human influences on subterranean ecosystems.

Conceptual Model Refinements

These conceptual models figured prominently in our vital signs scoping process. We used the models to organize workshop participants into breakout groups for the vital signs scoping workshop in May 2004 (and to provide a framework for the discussion in Chapter One of this report). Throughout the workshop, network staff consulted the conceptual models to develop monitoring questions and vital signs, or used them as a backdrop for considering the issues. Workshop participants, in turn, provided many useful comments for improving the models. Appendix G contains a report on the results of the vital signs scoping workshop.

Conceptual models are iterative. Although they should be based on fundamental and enduring principles of ecology, they should also be sufficiently flexible to allow refinement as the results of monitoring or other empirical or theoretical advances improve our understanding of the elements and processes of park ecosystems. In the development of this initial suite of conceptual models, our primary goal was to illustrate the primary influences on park ecosystems. We added additional details to illustrate the primary gradients, dynamics, and human influences structuring the major ecosystem domains. By design, we did not develop models of special habitats or focal animal or plant populations. We felt that highly constrained or focused models could not be developed for the many particular concerns in the network. With the selection of vital signs in Phase II, we have begun developing detailed conceptual models of particular vital signs that we hope will help illustrate the appropriate measurement to develop into long-term monitoring protocols.

CHAPTER THREE: VITAL SIGNS

3.1. Introduction

The concept of ecological integrity provides a framework for evaluating changing environmental conditions and biodiversity through monitoring (Karr, 1991, Dale and Breyeler 2001). Ecological integrity refers to three major concepts: (1) system wholeness, including the presence of appropriate species, populations, and communities; (2) the occurrence of ecological processes at appropriate rates and scales (Angermeier and Karr, 1994; Karr, 1991); and (3) environmental conditions that support these taxa and processes (Dale and Breyeler 2001). Known or hypothesized stressors may affect ecological integrity. The vital signs selected to monitor effects on ecological integrity are factors that reflect the park ecosystem's structure (referring to the organization or pattern of the system), function (referring to ecological processes), and composition (referring to the variety of elements in the system). They are a subset of the total suite of natural resources that park managers are directed to preserve unimpaired for future generations, including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic.

The scoping meetings and conceptual modeling described in the first two chapters of this plan resulted in a list of monitoring questions and potential vital signs. The purposes of this chapter are to: (1) explain the process by which the many potential vital signs that could be monitored were analyzed, rated and prioritized; (2) describe the vital signs that have been determined to be of highest priority for monitoring by the Network; (3) justify the highest priority vital signs; and (4) describe the vital signs that were not chosen, and why.

3.2. Prioritization of Vital Signs

The foundation of the Klamath Network's approach was to identify the most important monitoring questions to answer in relation to potential trends in ecosystem structure, function and composition in the parks. The full set of questions identified throughout the conceptual modeling and scoping processes is located in Appendix G, Tables 2-7. Each of these questions identified one or more possible related vital signs to monitor. Many were based on conceptual modeling of gradient structure, processes, and stressors in the Network ecosystems (see Chapter 2). Monitoring questions were developed specifically for each of the four main ecosystems in the Klamath Network (terrestrial, freshwater, marine, and subterranean). We did not use a park by park approach, although that approach was used by USGS in identifying water quality vital signs (section 3.2.3.). Some ecosystems or communities are present in only one park (e.g. marine in Redwood). Resources present in just one park were not considered less important.

To reduce the large list of questions down to the top priorities that could be feasibly monitored, we first removed or rephrased a number of research questions. Then, from the remaining set of questions, we selected a short list of 33 that were most frequently identified or stressed as important throughout the vital signs scoping process. The prioritization of vital signs was then accomplished through a formal ranking exercise, and follow-up workshop. The process was designed to produce an unbiased list of monitoring projects supported to the maximum extent possible by group consensus.

3.2.1. Vital Signs Ranking, Step 1

A. Rating monitoring questions

We asked 130 experts representing a broad array of scientific disciplines, many of whom had participated in vital signs scoping, to rank candidate vital signs. We sent these experts a database containing questions and vital signs to rank, as well as the specific criteria to use for ranking. The affiliations and disciplines of the 44 experts who responded to our request are shown in Table 3.1.

Table 3.1. Affiliations and expertise of the 44 respondents to the questionnaire sent out to rate monitoring questions and associated vital signs.

Affiliation	Count
Federal (non NPS)	6
Non Profit	2
NPS (KLMN Parks)	20
NPS (regional/national)	7
Other	2
University	5
Area of Expertise	
Aquatic Ecology & Systematics-Animals	3
Aquatic Ecology & Systematics-Plants	1
Geography-Biological	2
Microbiology	1
Natural Resources	9
Physical Science-Air Resources	2
Physical Science-Geology & Soils	5
Physical Science-Water Resources	1
Terrestrial Ecology & Systematics-Animals	8
Terrestrial Ecology & Systematics-Plants	12

As these numbers show, respondent's affiliations were weighted toward National Park Service and other government organizations, while disciplines were most often in the fields of terrestrial plant and animal ecology and systematics. There were no cave science respondents. There were relatively few respondents from academia. Many people were not comfortable rating phenomena outside their particular focused area of expertise.

Nonetheless, we feel that the rating provided useful guidance, with the exception that the importance of Cave resources may have been under-represented, despite their central ecological and management significance in Lava Beds and Oregon Caves. However, by identifying subterranean ecosystems as one of the 4 basic ecosystem types in the Klamath Network in our conceptual modeling and throughout Chapters 1 and 2, we helped ensure that these resources would not get overlooked in determining vital signs for monitoring. As described below, we specifically elevated the cave monitoring questions and vital signs for this reason. This helped ensure that the monitoring program will have environmental breadth. However, there was no attempt to divide vital signs selected equally among ecosystems.

Management and Ecological Significance. Experts were asked to rate the management and ecological significance of the 33 monitoring questions on the short list according to the criteria and scoring shown in the box below:

Management Significance Criteria

1. *The question addresses the need for information to be used in adaptive management aimed at maintaining ecosystem integrity in the Klamath Network.*
2. *The question addresses the kind of ecosystem changes that managers, policy makers, researchers and the public will recognize as important to ecosystem integrity.*
3. *The question addresses the need to provide an early warning of loss of ecosystem integrity that can be addressed through management actions.*
4. *The question addresses National Park Service performance goals.*
5. *The question addresses important information gaps in our understanding of how to manage and maintain the integrity of ecosystems of the Klamath Network.*

Ecological Significance Criteria

1. *The question addresses important changes to ecosystem structure that may occur.*
2. *The question addresses important changes to ecosystem function that may occur.*
3. *The question addresses important changes to ecosystem composition that may occur.*
4. *The question addresses the need to provide early warning of changes to ecosystem structure, function and composition that may occur.*
5. *Reference conditions exist or may be defined against which monitored changes can be measured or interpreted to describe changes in ecosystem integrity.*

Scoring

4- Very high: Strongly agree with all 5 statements
3 –High: Strongly agree with at least 4 statements
2 –Medium: Strongly agree with 2- 3 statements
1- Low: Strongly agree with only 1 statement
0- None. Strongly agree with none of these statements.

B. Ranking results—monitoring questions

Table 3.2. The 33 monitoring questions on the short list with their ranking scores.

Monitoring question	**Rank**	**Ecological significance average**	**Management significance average**	**Average of both scores**
What are the trends in distribution and abundance of non-native species through time?	1	3.43	3.46	3.44
What are status and trends in structure, function, and composition of focal communities?	2	3.44	3.14	3.29
What are the status and trends in anthropogenic disturbance?	3	3.21	3.35	3.28
What are status and trends in focal taxa groups (e.g. birds, fish, and amphibians)?	4	3.38	3.15	3.26
What are status and trends in focal species?	5	3.22	3.28	3.25
What are status and trends in surface waters (including pristine and 303d listed waters)?	6	3.26	3.07	3.16
What are the status and trends in natural disturbance events (e.g. fire, floods)?	7	3.28	3.03	3.15
What are status and trends in human impacts near sensitive plant and animal populations and habitats?	8	3.03	3.28	3.15
What are status and trends in pollutants (chemicals, nutrients, effluents, and trash)?	9	3.08	3.20	3.14
How are connectivity, fragmentation, and level of park "insularity" changing with land use change in and around the parks?	10	3.20	3.00	3.10
What are the long term trends in the predominant habitat types?	11	3.18	2.89	3.04
What are status and trends in pollutants (e.g. ozone, N, S, particulates)?	12	3.17	2.66	2.91
What are status and trends in ground waters?*	13	2.74	2.70	2.72
Are climate associated ecotones changing through time?	14	3.13	2.28	2.70

What are the trends in harvesting of park resources?	15	2.49	2.87	2.68
Have rates, extent, location, or types of erosional and depositional processes changed?*	16	2.76	2.59	2.68
What are the trends in diseases or parasites (including forest insects) through time?	17	2.92	2.42	2.67
How are snowpack dynamics changing over time?*	18	3.03	2.31	2.67
How is cave air flow (quantity and quality) changing through time?	19	2.60	2.48	2.54
What is timing and duration of key climate-related phenological events?*	20	2.95	2.05	2.50
How is sea level and ocean temperature changing?	21	3.00	2.00	2.50
How is woody debris production and storage changing over time?*	22	2.62	2.31	2.46
What are status and trends in soils?*	23	2.65	2.20	2.42
How are ocean and nearshore processes changing through time?*	24	2.77	2.00	2.38
What are the trends in pollinators?*	25	2.75	2.00	2.38
What are status and trends in subterranean water and ice?	26	2.43	2.29	2.36
What are the status and trends of biotoxin accumulation?*	27	2.57	2.10	2.34
What are status and trends in fog?*	28	2.61	1.77	2.19
What are status and trends in visibility?*	29	1.89	2.16	2.03
What are changes in extent of soil crust?*	30	2.19	1.84	2.02
What are the status and trends in subterranean geologic processes?	31	1.95	1.80	1.88
What are the status and trends in marine geologic processes?*	32	2.00	1.54	1.77
What is the effusion rate of geothermal groundwater into the surface environment?*	33	1.55	1.32	1.43

*Indicates questions that are not addressed by vital signs proposed for monitoring by the Klamath Network as a result of this ranking process. Additional ranking and considerations described below.

B. Ranking vital signs associated with monitoring questions

Respondents also rated the relevancy and suitability of vital signs associated with the each monitoring question. The list of 172 vital signs associated with the 33 monitoring questions is too lengthy to reproduce here; it is shown in Appendix L. Table 3.3 shows vital signs and associated questions from the final list of selected vital signs. Relevancy was ranked on a 0-4 scoring system based on the criteria and scoring shown in the following box.

Relevancy Criteria

1. *Measurable: Capable of being defined and measured.*
2. *Interpretable: Changes in the vital sign and their significance will be apparent.*
3. *Resource at risk.*
4. *Sensitive to change.*
5. *Comprehensive: indicator of broad-scale changes.*

Scoring

4: *Very High, meets all 5 criteria*
3: High, meets at least 4 criteria
2: Medium, meets 2- 3 criteria
1: Low, meets only 1 criterion
0: Very Low, meets none of the criteria
(Blank): No opinion, or did not score this vital sign

In addition to providing a ranking of monitoring questions and associated vital signs (Appendix L), many respondents provided insightful comments, which were encouraged by the design of the questionnaire. These comments are shown in Appendix M and Appendix N.

3.2.2. Vital Signs Ranking, Step 2

The next step was to consider legal/policy mandate and cost/feasibility of potential vital signs, factors that all networks considered, and also to address additional factors from the literature and lessons learned in other ecological monitoring. This was accomplished at a two day workshop in Redding, California on April 27-28, 2005, where the final selection of vital signs was accomplished. The specific purpose of the workshop was to review and evaluate the result of the ranking generated by the questionnaire and subsequent Klamath Network staff modification of the ranking. Members of the Network's Technical advisory Committee and other resource specialists from all six of the network Parks attended the workshop.

To guide the process of identifying final vital signs, Daniel Sarr, Klamath I&M Network Coordinator, provided a brief overview of lessons from the Northwest Forest Plan monitoring. He focused on those lessons germane to the Klamath Network. He noted the tremendous expense of monitoring a single species throughout the Pacific Northwest (for example, more than $25 M for the northern spotted owl over ten years). He also presented several possible shortcomings with species oriented monitoring: (1) individual or focal species may be poor indicators because they have not been tested in many cases, and cannot be assumed to describe changes among other species; and (2) despite their obvious conservation significance, rare species may not be good choices because they require excessive sampling intensity to detect changes (Manley 2004). He suggested some of these concerns could be addressed, in part, by sampling multimetric or community indices (e.g., Index of Biotic Integrity, etc. Karr 1981, Karr and Chu 1999).

Additional concepts identified for consideration during selection of vital signs included the following:

1. Conceptual Relevance--Is the indicator relevant to the assessment question (management concern) and to the ecological resource or function at risk?
2. Feasibility of Implementation--Are the methods for sampling and measuring the environmental variables technically feasible, appropriate, and efficient for use in a monitoring program?
3. Response Variability--Are human errors of measurement and natural variability over time and space sufficiently understood and documented?
4. Interpretation and Utility--Will the indicator convey information on ecological condition that is meaningful to environmental decision-making?

Taken together, the above considerations provided some conceptual sideboards to guide final vital signs selection. Other important issues included scope, cost-effectiveness, and collaboration potential.

Because of the large number of vital signs (172), a tentative ranking based on these round II criteria was developed by Network staff prior to the workshop. The Network's criteria for ranking vital signs based on legal and policy factors were essentially the same as recommended by the National I&M program, explained in the box below.

Legal and policy mandate ranking criteria

Very High: The park is required to monitor this specific resource/indicator by some specific, binding, legal mandate (e.g., Endangered Species Act for an endangered species, Clean Air Act for Class 1 airsheds), or park enabling legislation.

High: The resource/indicator is specifically covered by an Executive Order (e.g., invasive plants, wetlands) or a specific Memorandum of Understanding signed by the NPS (e.g., bird monitoring), as well as by the Organic Act, other general legislative or Congressional mandates, and NPS Management Policies.

Moderate: There is a Government Performance and Results Act (GPRA) goal specifically mentioned for the resource/indicator being monitored, or the need to monitor the resource is generally indicated by some type of federal or state law as well as by the Organic Act and other general legislative mandates and NPS Management Policies, but there is no specific legal mandate for this particular resource.

Low: The resource/indicator is listed as a sensitive resource or resource of concern by credible state, regional, or local conservation agencies or organizations, but it is not specifically identified in any legally-binding federal or state legislation. The resource/indicator is also indirectly covered by the Organic Act and other general legislative or Congressional mandates such as the Omnibus Park Management Act and GPRA, and by NPS Management Policies.

Very Low: The resource/indicator is covered by the Organic Act and other general legislative or Congressional mandates such as the Omnibus Park Management Act and by NPS Management Policies, but there is no specific legal mandate for this particular resource.

The criteria for ranking vital signs based on cost and feasibility factors, as well as the scoring are described in the following box:

Cost and feasibility ranking criteria

- *Sampling and analysis techniques are cost-effective. Cost-effective techniques may range from relatively simple methods applied frequently or more complex methods applied infrequently (e.g., data collection every five years results in low annual cost).*
- *The indicator has measurable results that are repeatable with different, qualified personnel.*
- *Well-documented, scientifically sound monitoring protocols already exist for the indicator.*
- *Implementation of monitoring protocols is feasible given the constraints of site accessibility, sample size, equipment maintenance, etc.*
- *Data will be comparable with data from other monitoring studies being conducted elsewhere in the region by other agencies, universities, or private organizations.*
- *The opportunity for cost-sharing partnerships with other agencies, universities, or private organizations in the region exists.*

4 Very High:	*Strongly agree with all 6 of the statements above.*
3 High:	*Strongly agree with 5 of the statements above.*
2 Medium:	*Strongly agree with 4 of the statements above.*
1 Low:	*Strongly agree with 3 of the statements above.*
0 Very Low:	*Strongly agree with 2 of the statements above.*
0 None:	*Strongly agree with 1 or fewer of the statements above.*

The overall ranking that resulted from considering all four criteria is shown in Appendix L. This was based on weighting of each criteria's score using the following equation:

(0.3 * Management Significance score) + (0.3 * Ecological Significance score) + (0.1* Relevancy score) + (0.1*Legal mandate score) + (0.2*cost & feasibility score) = final score

The effects of changing the weightings of each component score were explored both prior to and during the workshop.

The ranking shown in Appendix L was the starting point for the workshop attendees to select vital signs to be monitored. Following an explanation and review of the ranking results two groups were formed to independently adjust the influence of legal mandate and cost and feasibility issues in the overall ranking.

Each group began adjusting the vital signs ranking by giving legal mandate/policy a weight of zero. Both groups felt that we should recognize what we are mandated to monitor, but that the ranking criteria and scores for legal/policy mandate were hard to assign. Both groups then categorized each vital sign according to the ecosystem to which it applied (terrestrial, aquatic, marine, or subterranean). Both groups combined and selected vital signs that together would cover all 4 ecosystems of the Klamath Parks. Rare species were discussed and may be included in monitoring of keystone and sensitive species, despite the statistical challenges they pose, because of "management mandate." Management mandate also elevated water quality vital signs. Thus, legal/policy mandate did come into play, but only with regard to these specific vital signs. Each group was successful in combining and reducing the number of vital signs, and in picking the top 10-11 with coverage of all 4 ecosystems.

3.2.3. The Top Ten Network Vital Signs

The two groups reconvened and from the two lists of vital signs were able to select the top 10, representing the consensus of the meeting, as shown in the Table 3.3. The results of the separate effort by USGS to identify park specific Water Quality vital signs are described in Table 3.3.

Table 3.3. Klamath Network Top Ten vital signs and the portions of the National Park Service Ecological Monitoring Framework in which they occur. Each vital sign is presented with its ranking score and with associated monitoring questions that would be directly or indirectly addressed. These questions are numbered according to their rank. The main question is listed first. Other questions that would be addressed indirectly are then listed. These may not directly pertain to the national framework categories. National framework categories that contain no vital signs are not shown. Also shown are affected ecosystems (T = terrestrial, S = subterranean, F =freshwater aquatic, M=marine).

National I&M levels 1	National I&M level 2	National I&M level 3	Vital Sign	Vital Sign Score	Monitoring Questions Addressed	Affected Eco-systems
Biological Integrity	Invasive Species	-Invasive/ Exotic Plants -Invasive/ Exotic animals	**Non-native species**	3.52	1. What are the trends in distribution and abundance of non-native species through time? 2. What are status and trends in structure, function, and composition of focal communities? 11. What are the long term trends in the predominant habitat types?	T, F, M, S
	Focal species or communities		**Focal (keystone and sensitive) plants & animals**	3.39	5. What are the status and trends in focal species? 4. What are the status and trends in taxa groups? 15. What are the trends in harvesting of park resources? 17. What are the trends in diseases or parasites (including forest insects) through time?	T, F, M, S
		-Grasslands -Shrublands -Forests	**Terrestrial vegetation (major habitat types)**	3.39	2. What are status and trends in structure, function, and composition of focal communities? 11. What are the long term trends in the predominant habitat types? 1. What are the trends in distribution and abundance of non-native species through time? 14. Are climate associated ecotones changing through time?	T

		-Birds	**Bird Communities**	3.38	2. What are status and trends in structure, function, and composition of focal communities? 1. What are the trends in distribution and abundance of non-native species through time? (e.g. Barred Owl)	T, F, M
		-Intertidal Communities	**Intertidal Communities**	3.33	2. What are status and trends in structure, function, and composition of focal communities? 8. What are status and trends in human impacts near sensitive plant and animal populations and habitats? 3. What are status and trends in anthropogenic disturbances? 14. Are climate associated ecotones changing through time? 21. How is sea level and ocean temperature changing?	M
		-Aquatic vegetation -Wetland communities	**Aquatic Communities**	3.27	2. What are status and trends in structure, function, and composition of focal communities? 1. What are the trends in distribution and abundance of non-native species through time? (e.g. bullfrogs). 6. What are status and trends in surface waters? 8. What are status and trends in human impacts near sensitive plant and animal populations and habitats?	F
		-Cave Communities	**Cave entrance communities**	3.10	2. What are status and trends in structure, function, and composition of focal communities? 5. What are status and trends in focal species? 8. What are status and trends in human impacts near sensitive plant and animal populations and habitats?	S

Water	Water quality	-Water Chemistry	**Water quality**	3.30	9. What are status and trends in pollutants? 6. What are status and trends in surface waters?	F, M, S
Eco-system pattern and process	Landscape dynamics	-Land Cover and Use	**Land cover, use, pattern (roads)**	3.28	10. How are connectivity, fragmentation, and level of park "insularity" changing with land use change in and around the parks (human disturbance dynamics)? 3. What are status and trends in anthropogenic disturbances? 7. What are status and trends in natural disturbances? 2. What are status and trends in structure, function, and composition of focal communities? 5. What are the long term trends in the predominant habitat types?	T
Geology and soils	Subsurface geologic processes	-Cave features and processes	**Environmental Conditions in caves**	2.50	19. How is cave air flow (quantity and quality) changing through time? 2. What are status and trends in structure function and composition of focal communities? 8. What are status and trends in human impacts near sensitive plant and animal populations and habitats? 22. What are status and trends in subterranean water and ice? 31. What are the status and trends in subterranean geologic processes?	S

The process of identifying consensus on the top ten vital signs for monitoring resulted in a strong consolidation of many discrete vital signs into very broad ones (Table 3.3). This proved to be a good strategy for moving forward with consensus, and allowed the group to think programmatically, identifying vital signs groups that could clearly be implemented as an I&M subprogram. We also sought to develop a list with complementarity, recognizing that it will be necessary to monitor a broad and multifaceted suite of vital signs to effectively track ecological integrity in the diverse ecosystems of the Klamath Network. However, the specific attributes of vital signs that would likely be monitored under each broad vital sign need to be refined and spelled out based on budgeting reality. This was discussed at the meeting, with the results of the ranking exercise (Appendix L) providing guidance on what specific vital sign elements, attributes or characteristics should be monitored. The following section describes more specifically what is envisioned for the monitoring under each vital sign, and how the monitoring of some vital signs will complement that of other vital signs.

Non-native species. The goal of non-native species monitoring will be to identify and track invasions that can be managed. The status and trends of invasive exotic species of any kind were considered the most important vital sign of ecological integrity. Note that exotic diseases were not excluded and that native invasive species were not placed in this vital sign. This differs from the national framework level 3 classification, in which invasive/exotic plants and animals are recognized as distinct categories, but non-native diseases are not. Because non-native diseases specifically have caused some of the most profound losses of ecological integrity (e.g., complete loss of a dominant tree from the forests of the eastern U.S. due to Chestnut Blight), they were included here for possible monitoring.

However, it is non-native plants that have been identified as the biggest natural resource concern in most parks (Chapter 1). The Klamath Network is the study area for an ongoing research project, headed by Drs. T. Edwards and M. Brooks of the U.S. Geological Survey. This collaborative interagency project will develop a ranking of priority invasive plants for the network parks and model the habitats that will be at greatest risk from these plants. These modeling efforts, along with the exotic plant inventory already conducted by the Klamath I&M Program (Appendix I), will help focus exotic species monitoring on threats that can be managed.

There are three non-native diseases that are presently of concern (Appendix I), white pine blister rust, Port-Orford cedar root rot, and Sudden Oak Death. The species most affected by white pine blister rust, whitebark pine, is a keystone species that was identified as a monitoring priority under the Keystone and Sensitive Species vital sign. Status and trends in blister rust should be provided for under this monitoring. Port-Orford cedar root rot and Sudden Oak Death may not be monitored by the Network, but will be the focus of broad scale monitoring efforts by the states of California and Oregon.

The predominant invasive exotic animal threat is the bullfrog. It is anticipated that the status and trends in this species will be documented by the monitoring of amphibians, which were identified as the most important focal taxa group to monitor due to their sensitivity to stressors. Other invasive animals of concern include birds, such as the nest parasite the brown-headed cowbird and the barred owl a potential resource competitor of the spotted owl. These species would be tracked by monitoring under the bird communities vital sign.

Keystone and sensitive plants & animals. The goal of this monitoring would be to track trends in plants and animals in the Network that are considered of great importance due to their disproportionate role in ecosystem function, or their particular sensitivity to environmental change. A major task for Phase III that has begun is to identify specific keystone and sensitive plants and animals. The Network has identified park resource staff to meet and develop consensus and limits on which keystone and sensitive plants and animals will be specifically monitored. A number of candidate species, species groups, or ecosystem types have already been identified, including amphibians, whitebark pine, ponderosa pine, aspen, redwoods, freshwater mussels and other freshwater and marine invertebrates. Additional sensitive animals that have been shown to have the potential to be highly effective as indicators of changes in ecological integrity include ground arthropods (Kimberling et al. 2001), and small mammals (Manley 2004). Rare species that would be monitored based on management mandate need to be identified. The scope of monitoring under this vital sign may depend to a large extent on information on Keystone and Sensitive species obtained from other vital signs monitoring, particularly, vegetation and intertidal monitoring.

Terrestrial vegetation. The goal of this monitoring would be to track changes in the structure and composition of dominant natural vegetation. Standard vegetation sampling methods are envisioned with coverage of all major vegetation types on a regular basis. Because of the large area, and budget realities, a complete cycle of monitoring over the whole network could take many years, after which it would recommence. However, due to the relatively slow rate of vegetation change, aside from burned areas, locations of invasive species, etc. it is anticipated that this monitoring, along with land cover monitoring, will be able to sufficiently track vegetation change. Land Cover monitoring will identify areas where sampling in addition to that undertaken on a regular schedule may be needed due to vegetation change.

Bird Communities. The goal of this monitoring subprogram would be to track changes in populations of birds and the composition of bird communities, which can be related to changing environmental conditions. This monitoring would rely to a great degree on existing point count and mist net sampling protocols and interface with the Klamath Demographic Monitoring Network run by the Klamath Bird Observatory. As with vegetation coverage of all major habitat types would be covered on a regular, though not necessarily frequent, basis. Additional sampling protocols may need to be developed for marine and freshwater birds.

Intertidal Communities. The goal of this monitoring would be to track the condition of intertidal communities; particularly those exposed to human visitation impacts, such as tide pools. Existing repeatable and comparable intertidal community monitoring protocols are in place for western North America under the Partnership for

Interdisciplinary Studies of Coastal Oceans or PISCO (http://www.piscoweb.org/). This program's protocols should help form the basis of the Network's intertidal monitoring, and partnership and data sharing will be explored in Phase III. More intensive sampling, spatially and temporally, is envisioned where human impacts are greatest, but undisturbed reference sites will also need to be monitored.

Freshwater aquatic communities. The goal of this monitoring would be to track ecological integrity in select stream and lake communities. This monitoring will focus on focal aquatic resources such as macroinvertebrates (including mussels) and fish. Indices of biotic integrity for freshwater systems have been developed (Karr 1991) and will be useful in designing monitoring. The monitoring will target streams and lakes most impacted by human activities, as well as reference sites against which to compare changes detected. The water quality and keystone and sensitive species monitoring will complement this monitoring.

Cave collapse / entrance communities. The goal of this monitoring will be to track changes in the unique and sensitive cave collapse and cave entrance communities. Both unusual plant and animal assemblages characterize these communities at Lava Beds. Regular vegetation sampling protocols can be expanded to ensure thorough coverage of cave entrance communities under vegetation monitoring. Protocols for monitoring of bryophytes, lichens, and animals at the same locations where vegetation is sampled will need to be developed in Phase III.

Water quality (aquatic, marine, and subterranean). See Appendix F and Section 3.2.4.

Land cover, use, pattern (roads). The goal of this monitoring will be to track land cover change both in and around the parks. The Klamath Network held a remote sensing workshop in March 2005 specifically to explore how best to monitor land cover and use in and around the parks. Participants included USGS staff who have helped design remote sensing monitoring protocols (Robert Kennedy), as well as Bureau of Land Management staff who have used remote sensing data for a variety of monitoring purposes. We envision working with many of these experts who came together at the meeting during Phase III to develop specific protocols. Provisionally, there does not appear to be a need for very high spatial, temporal or spectral resolution to monitor the types of land use patterns around the Klamath Network parks, so existing LANDSAT or ASTER remote sensing platforms, complemented with aerial photo data appear to be sufficient. One key inventory need has been identified, baseline imagery data for Lava Beds. A contract was prepared to acquire these data in summer 2005, and they are currently being processed. Land cover monitoring will complement vegetation monitoring to provide coarse and fine scale data on vegetation change, disturbance, and possibly invasive plant dynamics.

Environmental conditions in caves. There is great concern over the deterioration of subterranean ecosystems as a result of human visitation. The goal of this monitoring would be to track changes in cave environments due to visitation and associated visitor use facilities. Cave experts were not at the final vital signs selection meeting. Those present at the meeting decided that a separate meeting with cave experts would be needed to determine specifically what parameters should be monitored and how. Water and ice will be monitored under Water Quality protocols.

3.2.4. Water Quality Vital Signs Selected by USGS using a Park by Park Approach

To better understand and organize the information currently available about the aquatic resources of each park unit, the Klamath Network developed an interagency agreement with the US Geological Survey to obtain technical assistance to (1) compile background information on the primary aquatic resources of each network park unit, including past and current monitoring efforts, and (2) draft the Phase II Water Quality Report (Appendix F).

The Water Quality Report provides an overview of the previous water quality related inventory and monitoring work conducted in each of the Network's six park units. It also provides guidance in the direction of future monitoring objectives. Activities undertaken to select vital signs for monitoring the aquatic resources of park units in the Klamath Network are also summarized. While many aquatic resource-related inventories have been conducted within the Klamath Network, some inventories have not been completed, most importantly a Marine inventory at Redwood (see Appendix F for explanation of extensive water quality inventories done in the parks). A Horizon Report (or Technical Report of Baseline Water Quality Information and Analysis compiled by the National Park Service's Water Resources Division) has also been completed for four network park units (Lassen, Lava Beds, Oregon Caves, and Whiskeytown). Each report contains information from several sources, including: (1) Storage and Retrieval water quality database management system (STORET); (2) River Reach File (RF3); (3) Industrial Facilities Discharge (IFD); (4) Drinking Water Supplies (DRINKS); (5) Water Gages (GAGES); and (6) Water Impoundments (DAMS). Each report provides: (1) a complete inventory of all retrieved water quality stations and parameter data, and the entities responsible for data collection; (2) descriptive statistics and appropriate graphical plots of water quality data characterizing period of record, annual, and seasonal central tendencies and trends; (3) a comparison of the park's water quality data to relevant water quality screening criteria; and (4) an Inventory Data Evaluation and Analysis to determine what Service-wide Inventory and Monitoring Program "Level I" water quality parameters have been measured within each study area. Horizon Reports can be downloaded from the National Park Service's Water Resource Division web site at: (http://www.nature.nps.gov/water/horizon.htm).

To date, over 100 aquatic inventory and monitoring related projects have occurred within the Klamath Network park units and surrounding public lands (Appendix F). These projects include information on aquatic biota (e.g. amphibians, fishes, and macroinvertebrates), baseline water quality (e.g. chemical and physical parameters), hydrological/ geological resources (e.g. surface flow, groundwater, and geothermal/hydrothermal), recreation effects, land use impacts, and watershed restoration.

Three conceptual models were developed for aquatic systems found in Klamath Network park units (Chapter 2): freshwater lentic, freshwater lotic, and marine ecosystems. The conceptual modeling process also identified many large-scale ecosystem-shaping processes, known as drivers. The definition of drivers is: major, naturally occurring forces of change that have large-scale influences on the attributes of natural systems. Drivers can be natural or human-induced and operate at large scales. The conceptual modeling process was particularly helpful in identifying proposed candidate vital signs that were not identified through other scoping processes (Appendix G). As described above the ecosystem-based vital sign scoping identified two of the 10 most important network-wide vital signs monitoring questions that were aquatic-resource focused (Table 3.2): What are the status and trends in pollutants? And, what are the status and trends in surface waters?

The dominant theme during the initial identification of network-wide water quality issues was aquatic ecosystem health. The importance of identifying a suite of vital signs useful for effective water quality assessment was underscored by: (1) the ability to document improvement (or lack thereof) in the water quality of Clean Water Act section 303(d) listed streams and outstanding natural resource waters; and (2) the ability of park unit managers to document progress toward achieving Government Performance and Results Act goal 1.a4 (i.e., that parks have unimpaired water quality). The need to fully inventory aquatic resources and document baseline and reference water quality conditions also were identified as important objectives in the development of a vital signs-based long term water quality monitoring program.

Detailed assessment and refinement of priority issues specific to KLMN water quality and the two aquatic resource-focused monitoring questions began in October 2004. The process was initiated by sending to the Chief of Resources Management of each park unit an Aquatic Resources and Water Quality Questionnaire. Park-specific information was sought in five basic categories: (1) identification of aquatic resources within park unit boundaries (i.e., marine, estuarine, lotic, lentic, palustrine, ice caves, and geothermal/ hydrothermal); (2) a list of water bodies of particular importance or interest to the park; (3) a list of past and current water quality monitoring efforts; (4) a list of water resource management and/or land use issues that impact resources from either within or outside each park unit; and (5) qualification of the level of knowledge and experience of park unit staff in monitoring water quality. Answers to the questionnaire categories were summarized into preliminary park-specific vital signs tables (Appendix F) that included columns for: (1) Aquatic Resource; (2) Potential Resource Stressors; (3) Potential Indicators of Stress; (4) Potential Monitoring Options; and (5) Stressor Priority. The tables were reviewed and refined at an aquatic resources vital signs scoping session held in December 2004.

Park unit staff identified the five most significant water quality resource management issues and aquatic resource stressors for each park (i.e., climate change, land use and non-recreational human impacts, introduced/invasive non-native biota, visitor recreational activities, and atmospheric deposition of nutrients and pollutants). In addition, the assessment process was instrumental for identifying indicators of aquatic resource stress, relative to the five identified stressors, and potential monitoring options for quantifying ecosystem health and/or disturbance. The park-specific and network-level results of this process are discussed in detail in Appendix F.

3.2.5. Justification for Vital Signs Selected

The vital signs selected have considerable breadth in the ecosystems and key monitoring questions they can address (Figure 3.1). In addition to involving all four major ecosystem types, the vital signs address 20 of the 33 monitoring questions that were sent out in the questionnaire, either directly or indirectly (Table 3.3, all questions listed except those with an asterisk). Each of the top 12 monitoring questions is addressed, in many cases by more than one vital sign (Table 3.4). The vital signs selected were also all identified in conceptual modeling (Chapter 2).

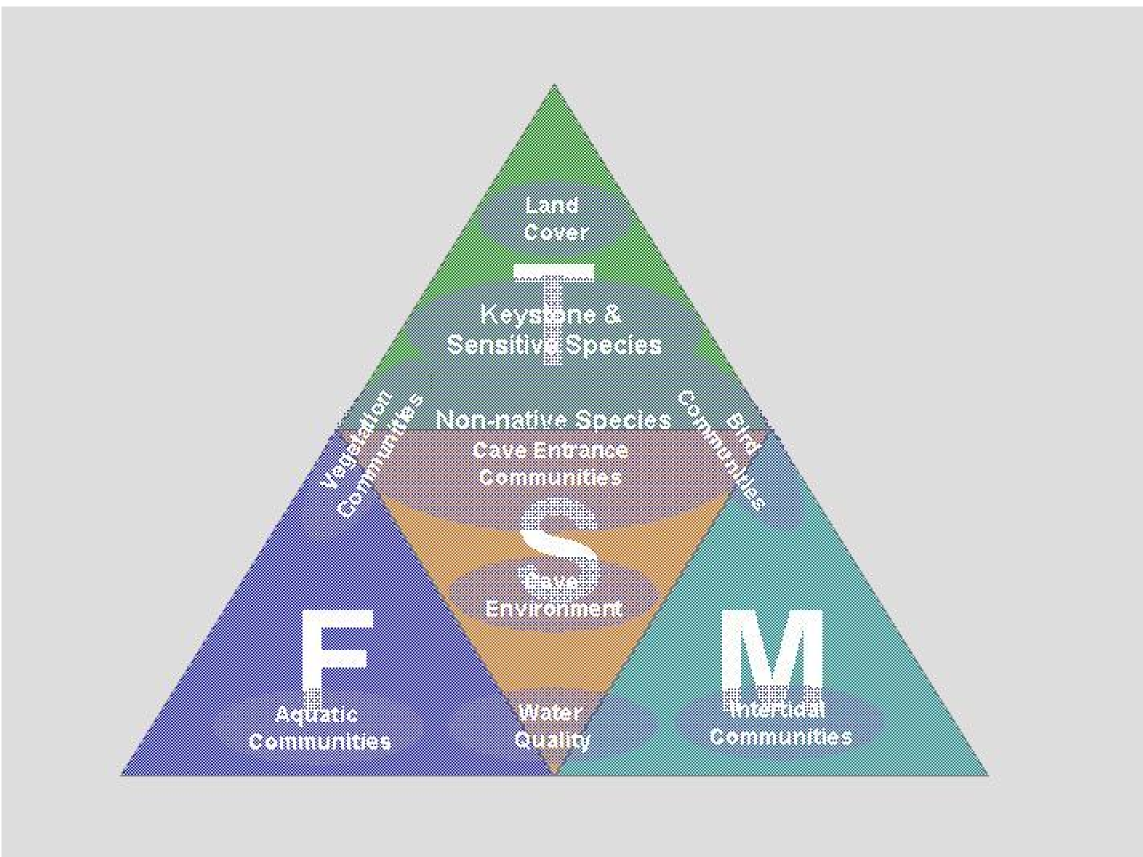

Figure 3.1. Conceptual model showing 4 major ecosystems and the top ten vital signs. Spheres in which vital signs are located indicate which ecosystems would be monitiored and illustrate generally how thorough monitoring would be in each of the major ecosystem types.

3.2.6. Vital Signs Considered and Not Selected

Of the 13 questions not addressed, the following are likely to be at least partially addressed by existing monitoring in the Parks and/or surrounding region by various entities (Appendix J) because they are resources or processes that directly affect society:

13. What are the status and trends in ground waters?
18. How are snowpack dynamics changing over time?
23. What are status and trends in soils?
24. How are ocean and nearshore processes changing through time?
27. What are the status and trends in biotoxin accumulation?
29. What are the status and trends in visibility?
32. What are the status and trends in marine geologic processes?

All of the vital signs selected were justified by being associated with monitoring questions that had high scores when the ranking results were tabulated, with the exception of cave environmental conditions. The question most clearly associated with this vital sign was only ranked 19th, with a score of 2.53 (Table 3.2). The cave environment vital sign was elevated in importance due to a recognized need to have monitoring in all major ecosystem types.

The top ten vital signs selected would address many of the monitoring concerns raised by the full suite of monitoring questions, with some important exceptions. Many of the questions that rated lowest were about geology and soils. The reason these rated low and were not selected was, in part, because they change slowly, they are not as affected by human activities, and many of them cannot be managed by National Park staff. Thus, they received low management significance scores (see comments received from those who participated in the ranking, Appendix M). Of perhaps greatest ecological significance among vital signs that were not selected are several related to climate change, such as status and trends in ecotones, snowpack, phenology, ocean temperatures and fog. These scored relatively high in terms of ecological significance, but low in terms of management significance. The criteria for rating management significance emphasized that the results should be useful in adaptive management. A number of respondents remarked that climate change could not be managed at the park level (Appendix M). As a consequence, climate change-related vital signs were not rated high in the overall ranking, and their ranking was not elevated at the April 27-28, 2005 workshop. Air quality vital signs also did not rate high and were not selected. The National Park Service does maintain several air monitoring stations in the Klamath Network, and neither rankings nor subsequent network discussions highlighted a need to augment existing monitoring. Also, it is known that most of the Network's parks have good air quality at the present time. Other vital signs not selected were not believed to be good enough indicators of changes in ecological integrity compared to other variables, at least in the Klamath Network parks, these included pollinators, biotoxin accumulation, resources harvested, diseases and parasites.

Disturbances, both natural and anthropogenic (especially impacts from park visitor use), were frequently mentioned in vital signs scoping and questions relating to these ranked in the top ten. There are no vital signs explicitly identified to directly monitor anthropogenic disturbances, but they will still be monitored directly and indirectly with the 10 vital signs selected (Table 3.3), and/or by other monitoring in the parks (Appendix J).

As mentioned above, it is also anticipated that monitoring by others will address several questions that will not be dealt with by the Network's vital signs monitoring. The remaining monitoring questions that do not appear as though they will be addressed at this time by the Network, individual parks or other entities are:

16. Have rates, extent, location, or types of erosional and depositional processes changed?
20. What is the timing and duration of key climate-related phonological events?
22. How is woody debris production and storage changing over time?
25. What are trends in pollinators?
28. What are the status and trends in fog?
30. What are changes in the extent of soil crust?
33. What is the effusion rate of geothermal groundwater into the surface environment?

In addition to scoring relatively low in terms of Ecological and Management Significance, most of these questions would involve monitoring vital signs that rated poorly in terms of cost and feasibility (Appendix L).

Despite the breadth of the vital signs that were selected, some important ones may be left out, for example, kelp forests. These are known to be sensitive to effects of changing climate (Paine et al. 1998). However, subtidal kelp forests are not abundant within the boundaries of Redwood National Park, and they did not rate well in terms of cost and feasibility. In addition, it will not be possible to monitor all of the focal taxa groups and species, particularly those that rate poorly in terms of cost and feasibility. Fortunately, many of these are already monitored to some extent (e.g., fish assemblages and bats).

3.2.7. Planning and Integration

An important challenge in designing a comprehensive monitoring program is integration of monitoring projects that overlap in the monitoring questions they address (Table 3.4). This is so that the interpretation of the whole monitoring program yields information more useful than that of individual parts (Jenkins et al. 2003). There are spatial, temporal and programmatic planning and integration considerations. The next step in the development process is to evaluate the ecological integration of the chosen vital signs and measurable attributes. It is important for ecological integration to carefully consider how attributes measured by each monitoring project provide information to other monitoring goals. This includes information needed to interpret the monitoring of each Vital Sign that can be provided by monitoring another Vital Sign. As described above for each vital sign, most monitoring has the potential to provide valuable information about other vital signs. In the following chapter, we will analyze how the timing and location of monitoring projects can be integrated and pursued via partnerships to maximize the efficiency and the value of information collected.

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